GROWING GREENHOUSE VEGETABLES IN ONTARIO

Publication 836

Ministry of Agriculture,
Food and Rural Affairs

Ontario

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Acknowledgements

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Introduction

The Ontario greenhouse vegetable sector is a very advanced, technical sector of agriculture that requires a good understanding of the scientific principles of plant production, the ability to manage the greenhouse environment through the use of computers and the ability to manage labour to obtain the maximum return on investment.

Growers who are willing to adopt new ideas and technologies can reap economic benefits while ensuring their production methods are environmentally sustainable.

Growing Greenhouse Vegetables in Ontario is designed to be a technical resource for greenhouse vegetable producers. The recommendations in this publication are based on applied research conducted at the Greenhouse and Processing Crops Research Centre (GPCRC) by Agriculture and Agri-Food Canada (AAFC) and Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) staff, at Vineland Research Station by OMAFRA staff and University of Guelph researchers and through grower trials. This publication was prepared in consultation with:

- Ontario Soil Management Services Committee

and personnel of:

- Agriculture Development Branch, OMAFRA
- University of Guelph
- AAFC (Harrow)

OMAFRA has far more information available than can be included in this publication. Additional or updated information can often be found in the greenhouse section of the OMAFRA website (www.ontario.ca/crops).

Please note that this book does not provide recommendations regarding specific pesticide products for the control of insects, diseases and weeds. For specific information, see OMAFRA Publication 835, *Crop Protection Guide for Greenhouse Vegetables* and Publication 75, *Guide to Weed Control.* Information on ordering these and other OMAFRA publications is found at the beginning of this book. Supplements to these publications will be posted to the OMAFRA website at www.ontario.ca/crops.

Contents

Introduction iii

1. Factors Affecting Greenhouse Production 1

Vegetative or Generative Plants 1
Temperature 1
Photosynthesis and Respiration 1
Rate of Development of Leaves, Flowers and Roots 2
Shape and Development 2
Humidity 2
Temperature Management 2
Light 4
Interaction Between Light Intensity and Plant Leaf ... 5
Light Transmission 5
Relative Humidity (RH) 6
Vapour Deficit or Vapour Pressure Deficit 7
Carbon Dioxide (CO_2) 9
Methods to Increase CO_2 9
Energy Conservation 9
Water 10
Nutrient Solution Recycling 12
Nutrient Solution Disinfection 12
Slow Sand Filtration 13
Lava Rock Filtration 13
Heat Treatment 13
Ozonation 13
Ultraviolet (UV) Treatment 14

2. Analytic Testing 15

Nutrient Solution and Analyses 15
Tissue/Foliar Testing 15
Soil Testing 15

3. Growing Media 17

Rockwool Culture 17
Open System 18
Closed System 18
Raised Trough System 19
Water Management 19
Fertilizer Schedules 21
Slab Sterilization 21
Coir or Coco Peat 21
Nutrient Film Technique (NFT) 22
Reservoir Tank 22
Pump System 22
pH and EC Controllers 23
Temperature Control 24
Disinfection 24
Aeration 24
Plumbing for Nutrient Solution Distribution and Collection 24
Growing Trough 25
Phytotoxicity 26
Soil Culture 26
Type of Soil 26
Drainage 26
Flooding and Leaching 26
Soil Pasteurization 26
Organic Matter 27
pH Control 27
Drip Irrigation 28

4. Plant Raising 29

Seed 29
Sowing and Germination 29
Transplant Raising 31
When to Water 32
Grafting 32

5. Tomato 35

Cultivars 35

Cropping Schedule 36

Seeding 36

Plant Raising 37

Plant Spacing 37

Pruning and Training 38

Cluster Pruning 38

Pollination 39

Bumblebees 39

Climate 40

Nutritional Requirements 41

Nitrogen (N) 43

Potassium (K) 43

Phosphorus (P) 44

Magnesium (Mg) 44

Calcium (Ca) 44

Sulphur (S) 44

Iron (Fe) 44

Manganese (Mn) 44

Copper (Cu) 44

Boron (B) 45

Zinc (Zn) 45

Molybdenum (Mo) 45

Harvesting and Storage 45

6. Cucumber 47

Cultivars 47

Cropping Schedule 47

Seeding 48

Plant Raising 48

Plant Spacing 48

Growing Media 48

Crop Training 49

System 1 49

System 2 49

Fruit Pruning 50

Climate 50

Harvesting and Storage 51

7. Pepper 55

Cultivars 55

Cropping Schedule 55

Seeding 55

Plant Raising 55

Plant Spacing 55

Growing Media 56

Pruning and Training 56

Climate 58

Fruit Set 58

Harvesting and Storage 59

8. Lettuce 61

Cultivars 61

Seeding 61

Plant Raising 62

Plant Spacing 62

Crop Production 62

Climate 63

Harvesting and Storage 63

9. Eggplant 65

Cultivars 65

Cropping Schedule 65

Seeding 65

Plant Raising 65

Plant Spacing 66

Growing Media 66

Pruning and Training 66

Climate 66

Fruit Set 66

Harvesting and Storage 66

10. Integrated Disease Management .. 69

The Disease-Triangle Concept 69

Six Principles for Plant Disease Management 69

Exclusion 69

Avoidance 69

Resistance 69

Protection/Prevention 69

Eradication 70

Therapy 70

Basic Integrated Disease Control Strategies 70

Environmental Manipulation 70

Modification of Cultural Practices 70

Sanitation and Roguing 70

Cleaning and Disinfecting 71

Pathogen-Free Plant Material 72

Vector Control 72

Resistant Cultivars 72

Chemical Control 72

Biological Control 72

Success Criteria 73

11. Diseases 75

Tomato 75

Tomato Diseases Caused by Fungi 75

Tomato Diseases Caused by Bacteria 77

Tomato Diseases Caused by Viruses 79

Tomato Physiological Disorders 80

Cucumber 82

Cucumber Diseases Caused by Fungi 82

Cucumber Diseases Caused by Bacteria 84

Cucumber Diseases Caused by Viruses 84

Cucumber Physiological Disorders 85

Pepper 85

Pepper Diseases Caused by Fungi 85

Pepper Diseases Caused by Bacteria 85

Pepper Diseases Caused by Viruses 86

Pepper Physiological Disorders 86

Lettuce 87

Lettuce Diseases Caused by Fungi 87

Lettuce Physiological Disorders 87

Eggplant 88

Eggplant Diseases Caused by Fungi 88

Eggplant Physiological Disorders 88

12. Integrated Pest Management (IPM) 89

Monitoring 89

Sticky Traps 89

Crop Inspection 89

Cultural Controls 90

Sanitation 90

Environmental Manipulation 90

Physical Control 90

Screening 90

Yellow Sticky Tape 91

Light Traps 91

Biological Control 92

Chemical Control 95

Resistance 95

Pesticide Application 96

Pesticide Compatibility 96

13. Insect, Mite and Other Pests 97

Thrips 97

Description and Life History 97

Damage 97

Control Strategies 97

Whiteflies 98

Description and Life History 98

Species of Whiteflies 99

Damage 99

Control Strategies 99

Two-Spotted Spider Mites 101

Description and Life History 101

Damage 101

Control Strategies 101

Tomato Russet Mites (TRM) ... 102
Description and Life History ... 102
Damage ... 103
Control Strategies ... 103
Cyclamen/Broad Mites ... 103
Description and Life History ... 103
Damage ... 104
Control Strategies ... 104
Aphids ... 104
Description and Life History ... 104
Damage ... 105
Control Strategies ... 105
Cabbage Loopers ... 106
Description and Life History ... 106
Damage ... 106
Control Strategies ... 106
Lygus Bugs ... 106
Description and Life History ... 106
Damage ... 106
Control Strategies ... 107
European Corn Borers ... 107
Description and Life History ... 107
Damage ... 107
Control Strategies ... 107
Fungus Gnats/Shoreflies ... 108
Description and Life History ... 108
Damage ... 108
Control Strategies ... 108
Tomato Pinworms ... 109
Description and Life History ... 109
Damage ... 109
Control Strategies ... 110
Potato Psyllids ... 110
Description and Life History ... 110
Damage ... 110
Control Strategies ... 110
Leafminers ... 111
Description and Life History ... 111
Damage ... 111
Control Strategies ... 111
Occasional Greenhouse Pests ... 112
Ants ... 112
Caterpillars ... 112
Grasshoppers ... 112
Root Nematodes ... 112
Slugs and Snails ... 113
Sowbugs and Pillbugs ... 114
Springtails ... 114
Striped Cucumber Beetles ... 114
Symphylans ... 115
Vertebrate Pests ... 115
Weed Control ... 115
Herbicides ... 115

14. Appendices ... 117

Appendix A. OMAFRA Greenhouse Vegetable Staff ... 117
Appendix B. Diagnostic Services ... 118
Appendix C. Other Contacts ... 120
Appendix D. Soil Testing Labs in Ontario ... 122
Appendix E. Ontario Ministry of the Environment Regional Contact Information ... 123
Appendix F. The Metric System ... 124

List of Tables

TABLE 1–1. Conversion Table for Light 6
TABLE 1–2. Water Content of Air at 18°C for Various Humidities 7
TABLE 1–3. Effect of Temperature on the Saturated Water Content of Air 7
TABLE 1–4. Vapour Pressure Relations 7
TABLE 1–5. The Relationship of VPD (mbars) to Temperature and RH 8
TABLE 1–6. Classification of Water Quality 11
TABLE 2–1. A Guide to Nutrient Content of Leaf Tissue 16
TABLE 2–2. Guidelines for Greenhouse Growing Media Analyzed by the Saturated Media Extraction (SME) Method 16
TABLE 3–1. Time–Temperature Requirements to Destroy Undesirable Organisms 27
TABLE 4–1. Seed Germination Categories 29
TABLE 4–2. Seed Requirements 29
TABLE 4–3. Germination Temperatures 30
TABLE 4–4. Approximate Hours for Germination 30
TABLE 5–1. Cropping Schedule for Tomatoes 36
TABLE 5–2. Recommended Air Temperatures (°C) for Tomatoes 40
TABLE 5–3. TOMATOES: Summary of Growing Recommendations 41
TABLE 5–4. Fertigation Schedule for Tomato (ppm nutrient) 42
TABLE 5–5. Weights of Fertilizer Required to Make Stock Nutrient Solutions 43
TABLE 6–1. Fruit Load on Young Cucumber Plants 50
TABLE 6–2. Temperature (°C) Regime for Cucumber Production 51
TABLE 6–3. CUCUMBERS: Summary of Growing Recommendations 52
TABLE 6–4. Fertigation Schedule for Cucumber (ppm nutrient) 52
TABLE 6–5. Weights of Fertilizer Required to Make Stock Nutrient Solutions 53
TABLE 7–1. Fertigation Schedule for Peppers (ppm nutrient) 56
TABLE 7–2. Weights of Fertilizer Required to Make Stock Nutrient Solutions 57
TABLE 7–3. PEPPERS: Summary of Growing Recommendations 59
TABLE 8–1. Fertigation Schedule for NFT Lettuce (ppm nutrient) 64
TABLE 8–2. Weights of Fertilizer Required to Make Stock Nutrient Solutions 64
TABLE 9–1. Long-Crop Schedule for Eggplant 65
TABLE 9–2. EGGPLANTS: Summary of Growing Recommendations 67
TABLE 12–1. Biocontrol Agents for Major Greenhouse Pests 93
TABLE 12–2. Reported Effects of Registered Insecticides/Miticides on Biological Control Agents 94
TABLE 12–3. Reported Effects of Registered Fungicides on Biological Control Agents 94

List of Figures

FIGURE 1–1. Temperature Profile for Greenhouse Crops — Sunny Days 3
FIGURE 1–2. Temperature Profile for Greenhouse Crops — Cloudy Days 3
FIGURE 1–3. Sunshine Hours — 75-Year Average 4
FIGURE 1–4. Global Radiation — Weekly Average 5
FIGURE 1–5. Global Radiation — 10-Year Average 5
FIGURE 1–6. Comparison of Light Transmission Between Glass and Double Polyethylene 5
FIGURE 1–7. Water Application in Greenhouse Vegetables 10
FIGURE 1–8. Nutrient Solution Recycling Layout 12
FIGURE 3–1. Layout for Open-System Rockwool 18
FIGURE 3–2. Layout for Closed-System Rockwool 18
FIGURE 3–3. Drainage Slits on Rockwool Slab for Tomato 20
FIGURE 3–4. Leachate Measurement 20
FIGURE 3–5. NFT Tank Setup 23
FIGURE 3–6. Layout for NFT Emitters and Return Line 25
FIGURE 4–1. Schematic of Japanese Top Grafting 33
FIGURE 6–1. Cucumber Pruning System 1 49
FIGURE 6–2. Cucumber Pruning System 2 49
FIGURE 8–1. Lettuce Yield Projection for Southwestern Ontario 61
FIGURE 8–2. NFT Layout for Lettuce 62
FIGURE 8–3. Floating Raft Production System 63

Colour Plates

Plate 1. A balanced tomato plant. 127
Plate 2. A vegetative tomato plant. 127
Plate 3. Grow pipe located at maturing fruit 127
Plate 4. A modern greenhouse with higher gutter height and peak-roof profile. 127
Plate 5. An older-style greenhouse with low gutter height and rounded-roof profile 127
Plate 6. Above-ground nutrient solution tank. 127
Plate 7. Below-ground nutrient solution tank. 128
Plate 8. Lava filtration system. 128
Plate 9. Heat pasteurization unit. 128
Plate 10. Ozonation unit. 128
Plate 11. Ultraviolet filtration 128
Plate 12. Basic setup for rockwool production 128
Plate 13. Raised trough system. 129
Plate 14. Rockwool slabs ready for steaming. 129
Plate 15. Steaming of rockwool slabs. 129
Plate 16. Setup for seed germination. 129
Plate 17. Transplant raising. 129
Plate 18. Rootstock ready for grafting 129
Plate 19. Rootstock with top removed. 130
Plate 20. Rootstock with clip added 130
Plate 21. Scion placed in clip 130
Plate 22. Finished graft topped at cotyledon leaf transplant. 130
Plate 23. Finished graft with two stems ready to transplant. 130
Plate 24. Flower development — stalk slightly too long 130
Plate 25. Split cluster due to low night temperature at the early bud development stage. 131
Plate 26. Tomato truss too long, resulting in kinking of stalk. 131
Plate 27. Truss support to prevent kinking. 131
Plate 28. Bumblebee visiting tomato flower. 131
Plate 29. Tomato flower showing marks caused by bumblebee visit — an indication of good pollination. 131
Plate 30. Tomato flower damaged by too many bumblebee visits. 131
Plate 31. Cucumber ready for transplanting. 132
Plate 32. Young pepper plant showing split stem and first flower (king flower) on the first level. 132
Plate 33. Sunscald. 132
Plate 34. Sunscald on pepper surface due to poor canopy and direct light on fruit surface 132
Plate 35. Elephant's foot as a result of damage from the accumulation of salts at the base of the plant. 132
Plate 36. Multi-stem eggplant to maintain plant balance and control height. 132
Plate 37. Strong eggplant flower for rapid fruit production. 133
Plate 38. High humidity in the greenhouse causing water condensation. This increases the incidence of gummy stem blight, Botrytis grey mould and Penicillium stem rot. 133
Plate 39. Damping-off. 133
Plate 40. Fusarium crown and root rot. 133
Plate 41. Grey mould. 133
Plate 42. Grey mould ghost spot. 133
Plate 43. Powdery mildew on tomato leaf. 134
Plate 44. Powdery mildew on tomato seedlings. 134
Plate 45. Large paper-like symptoms due to late blight on tomato plant. 134
Plate 46. Dark, greasy lesion due to late blight on tomato fruit. 134
Plate 47. Bacterial canker — one-sided wilt. 134
Plate 48. Bacterial canker — fruit mottling. 134
Plate 49. Bacterial stem rot. 135
Plate 50. Leaf symptoms of Pepino mosaic virus in tomato. 135
Plate 51. Leaf symptoms of Pepino mosaic virus in tomato. 135
Plate 52. Leaf symptoms of Pepino mosaic virus in tomato. 135
Plate 53. Leaf symptoms of tomato spotted wilt virus in tomato. 135
Plate 54. Blossom end rot. 135
Plate 55. Blotchy ripening due to low potassium. 136
Plate 56. Tomato pointy fruit. 136
Plate 57. Magnesium deficiency. 136
Plate 58. Environmental stress resulting in poor calcium and potassium movement to leaf's edge 136
Plate 59. Iron deficiency. 136
Plate 60. Iron deficiency due to poor root environment as a result of overwatering. 136
Plate 61. Boron deficiency. 137
Plate 62. Russetting. 137
Plate 63. Green shoulder. 137
Plate 64. Grey mould. 137

Plate 65. Gummy stem blight on stem. 137

Plate 66. Gummy stem blight on fruit. 137

Plate 67. Penicillium stem rot. 138

Plate 68. Leaf spot. 138

Plate 69. Powdery mildew on cucumbers. 138

Plate 70. Cucumber downy mildew. 138

Plate 71. Fusarium wilt of cucumbers. 138

Plate 72. Cucumber mosaic on leaf. 138

Plate 73. Cucumber mosaic on fruit. 139

Plate 74. Early symptoms of cucumber necrosis virus in cucumber. 139

Plate 75. Late symptoms of cucumber necrosis virus in cucumber. 139

Plate 76. Beet pseudo-yellows virus. 139

Plate 77. Loss of growing point caused by calcium deficiency due to low calcium supply and rapid growth on young cucumber shoots. 139

Plate 78. Young cucumber leaf showing iron deficiency symptoms due to rapid growth and heavy fruit load. 139

Plate 79. Iron deficiency. 140

Plate 80. Botrytis rot. 140

Plate 81. *Botrytis* on pepper fruit. 140

Plate 82. Stem symptoms of Fusarium stem and fruit rot. 140

Plate 83. Fruit symptoms of Fusarium stem and fruit rot. 140

Plate 84. Powdery mildew. 140

Plate 85. Bacterial soft rot of peppers. 141

Plate 86. Internal fruit rot in pepper. 141

Plate 87. Pepper mild mottle virus. 141

Plate 88. Leaf symptoms of tomato spotted wilt virus in pepper. 141

Plate 89. Blossom end rot. 141

Plate 90. Fruit cracking due to internal growth. 141

Plate 91. Fruit cracking due to internal growth (cross-section). 142

Plate 92. Silvering on pepper fruit. 142

Plate 93. Manganese deficiency. 142

Plate 94. Boron deficiency. 142

Plate 95. *Botrytis* on eggplant fruit. 142

Plate 96. Sepal ring on eggplant, resulting in unmarketable fruit. 142

Plate 97. Western flower thrips (lower left) and *Echinothrips* (upper right). 143

Plate 98. Thrips damage to fruit, oviposition damage. 143

Plate 99. Tomato spotted wilt virus. 143

Plate 100. Whiteflies. 143

Plate 101. Two-spotted spider mite with eggs. 143

Plate 102. Two-spotted spider mite damage on cucumbers. 143

Plate 103. Tomato russet mite on stem. 144

Plate 104. Feeding damage symptoms due to cyclamen mite on peppers. 144

Plate 105. Feeding damage symptoms due to broad mites on cucumber. 144

Plate 106. Green peach aphids. 144

Plate 107. Sooty mould caused by aphid infestation on cucumbers. 144

Plate 108. Cabbage loopers. 144

Plate 109. Lygus bug. 145

Plate 110. European corn borer. 145

Plate 111. Visual damage caused by European corn borer in peppers. 145

Plate 112. Fungus gnat. 145

Plate 113. Adult rove beetle. 145

Plate 114. Leaf damage caused by tomato pinworm. 145

Plate 115. Close-up of tomato pinworm larvae. 146

Plate 116. Fruit damage caused by tomato pinworm. 146

Plate 117. Nymphal stages of potato psyllids. 146

Plate 118. Leafminer damage on tomato. 146

1. Factors Affecting Greenhouse Production

Maximizing production and quality in a greenhouse operation requires proper management and control of plant growth. The major objective of a greenhouse is to provide an environment for optimum plant growth. Light is often considered the limiting factor; therefore greenhouses are built to maximize light penetration to maintain growth during the darker months. Other factors such as temperature, water, nutrition, insect and disease pressures and the crop and cultivars grown are also key components affecting growth and yield.

Control can be imposed on the plant by manipulating some of these factors, although others are either uneconomical or impossible to manipulate. For example, it is not economical to supplement prevailing low light levels in winter, except during seedling or plant-raising stages. However, during the summer when light levels are high, growers frequently reduce light transmission to the crop by using shade curtains or whitewashing the greenhouse exterior.

This chapter discusses some of the growth factors related to greenhouse production and how they influence vegetative and generative growth.

Vegetative or Generative Plants

By adjusting light, temperature, water and nutrient regimes, growers can shift plants from a vegetative phase to a generative phase or vice versa to ensure that a certain form or look of plant is obtained.

A *vegetative* plant produces more leaves than flowers and fruit. In this case, the plant has:

- large, thick, dark-green leaves and a thick stem with a light-green tinge at the growing point
- large, rough flowers on weak flower stems and trusses
- fruit that is small relative to the size of the plant
- extensive root growth (in some cases)

In contrast, a *generative* plant has:

- smaller leaves and a thin stem with a purple tinge at the growing point
- smaller, more numerous flowers that are prominently displayed
- fruit that is large compared to the size of the plant
- potentially poor fruit quality due to over-exposure to the sun

A balance between these two types of plants is optimal *(Plates 1, 2).*

Early in the planting cycle, plants tend to be vegetative. Control must be implemented early to obtain a generative plant that will provide fruit at the desired time. If plants become too generative, however, adjustments must be made to the cropping strategies to encourage more vegetative growth.

A plant grown at low temperature and high humidity during early winter, when light levels are traditionally low, tends to be vegetative if it receives plenty of water and nutrition. By raising the temperature (within reason) and decreasing the humidity, water and nutrition, a more controlled plant may be obtained.

Further changes may be made to the way the plant grows by adjusting the day-night temperatures. During hours of sunshine, a higher temperature allows the plant to manufacture sugars and grow rapidly. At night, lower temperatures allow the sugars manufactured during the day to be translocated or stored in the growing points of the stem and roots, the fruit and the leaves, resulting in thicker, heavier plants. Regularly adjusting the temperature and determining when to make these adjustments will result in a well-balanced, highly productive crop.

Temperature

Plant temperature influences several important processes that affect growth: photosynthesis, development of leaves, flowers and roots, plant shape and development, and relative humidity. These are described below.

Photosynthesis and Respiration

Photosynthesis is the process whereby plants use certain wavelengths of sunlight (photosynthetically active radiation or PAR) to convert carbon dioxide and water into carbohydrates and oxygen. The plant then stores the carbohydrates, which serve as a source of energy.

Respiration is the process whereby those carbohydrates are converted back into carbon dioxide and water, releasing energy. This energy is then used in processes such as the initiation and development of roots, leaves and buds. Respiration does not depend on light, taking place 24 hours a day. The rate of respiration is influenced by temperature.

The net effect of the two processes is plant growth, which can be expressed as an accumulation of dry matter. The optimum temperature to increase dry matter depends on light intensity. The higher the light intensity, the higher the optimum temperature. For most greenhouse crops, this optimum is between 12–16°C during low light conditions and 15–25°C when light intensity is high.

Rate of Development of Leaves, Flowers and Roots

The development of leaves, flowers and roots requires energy provided by respiration. Respiration, in turn, is influenced by temperature. For each degree Celsius increase between 10°C and 30°C, there is a corresponding 10% increase in leaf and flower initiation. Thus, the 24-hour average temperature determines the rate of crop development. Growers should lower the 24-hour average temperature under low light conditions and increase it under high light conditions.

Growers should observe the morphological characteristics of the plant to determine how to adjust the greenhouse temperature. At a low 24-hour average temperature, the plant tends to have shorter internodes, thicker stems and leaves and large flowers. At a high 24-hour average temperature, the plant tends to have longer internodes, thinner stems and leaves and small, spindly flowers. The goal is to strike a balance between the two, since high 24-hour average temperatures weaken the plant and flowers, causing yield reduction, while low 24-hour temperatures delay harvest or damage flowers, resulting in malformed fruits.

Shape and Development

The temperature influences the size and shape of leaves. For example, cucumbers and lettuce have short, wide leaves when temperature at initiation is low, while at high temperatures, the leaves are long and narrow.

The day-night temperature differential also affects the plant's shape. A small or zero day-night temperature differential results in more vegetative plants with short internodes and thicker, larger leaves *(Plate 2)*; a large day-night temperature differential results in more generative plants with longer internodes and thinner, smaller leaves. Growers should keep day temperatures close to night temperatures to encourage plant establishment in early development. However, after the flowering and fruit-setting stages, apply a differential.

Humidity

Temperature has an inverse effect on humidity. When temperature increases, relative humidity (RH) decreases. The reverse is also true. Relative humidity also has an inverse effect on the transpiration rate and, therefore, on the water status of the plant. In general, plants grown at high RH have larger leaves and longer stems than those grown at a lower RH.

Temperature Management

The optimum temperature for each crop depends on light conditions, the stage of growth and the season. By adjusting greenhouse temperatures, growers can control the rate of crop growth, its vigour, the shape or morphology of the plants, fruit size and, ultimately, yield. Generally, the optimum 24-hour temperature for lettuce is 17–18°C; tomatoes, 19°C; peppers, 19°C; and cucumbers, 21°C. However, in practice several temperature schemes have proven beneficial.

Figure 1–1, *Temperature Profile for Greenhouse Crops — Sunny Days* and Figure 1–2, *Temperature Profile for Greenhouse Crops — Cloudy Days* provide examples of manipulating temperature to develop the ideal plant with good form and high-quality production by maintaining an optimal 24-hour average temperature but raising the afternoon temperature to increase speed of growth and lowering it in the early night to create a strong head, root and fruit base.

Figure 1-1. Temperature Profile for Greenhouse Crops — Sunny Days

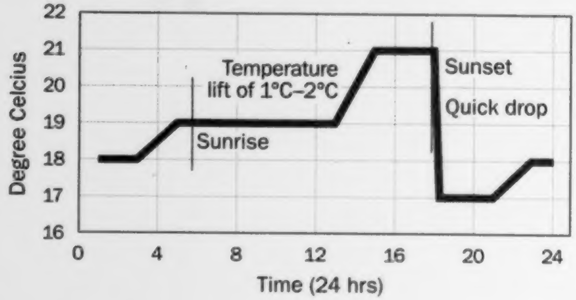
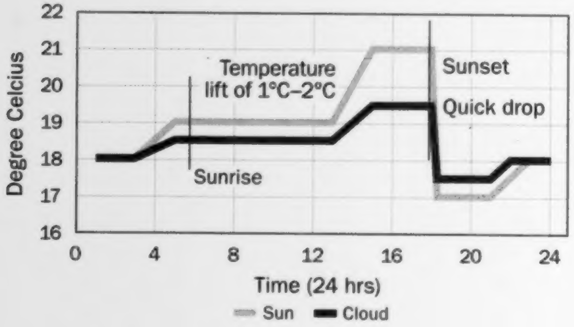


Figure 1-2. Temperature Profile for Greenhouse Crops — Cloudy Days



Heating

The hourly and yearly heating requirements for a greenhouse range can be calculated based on inside and outside temperatures, the type of glazing material and the surface area of the greenhouse. Greenhouse heating companies will design systems suitable for local conditions. The standard recommendation for a 35°C temperature differential is 350 watts of heat energy per square metre of space (W/m^2) for a glass greenhouse and 270 W/m^2 for a double polyethylene greenhouse. In southwestern Ontario, a 100-hp (981 kW) boiler is generally considered big enough for 0.4 ha of greenhouse. If thermal curtains are installed, these figures can be reduced by 25–35%.

Temperature requirements of major greenhouse vegetable crops (i.e., tomatoes, cucumbers, peppers and lettuce) vary significantly. Although some crops (e.g., lettuce) require less heat than others, heat requirements for a high-temperature crop should be accommodated in the design of the heating system so growers can easily switch crops at a later date.

The most common heating system in Ontario greenhouses is a central heating system. The source of energy is usually natural gas, with some growers using wood chips (waste wood) or pelletized fuel composed of wood, purpose-grown crops or agricultural residues. Bunker oil and #2 oil are frequently used as a standby, although a few growers use it as their main source of energy. Several growers use propane, especially those not close to natural gas supply lines.

Heat is provided in the form of steam or hot water that is produced by a centrally located boiler and distributed through a system of heating pipes. The main advantage of such a system is that the pipes can be located in the perimeter, where the greatest heat losses occur, or where it is most efficient (i.e., within the crop — about 30–60 cm above the ground). The greatest benefit of hot water systems is the ability to regulate the temperature of the water within the pipes, which are located within the crop to help maintain good air movement around the plants and can also be used as a pipe rail system for battery/electric-powered carts that improve labour efficiency. Grow pipes (small-diameter pipes located 50 cm above the growing row within the crop canopy) improve energy efficiency and decrease disease incidence *(Plate 3).*

Gas-fired unit heaters are an alternative to a central heating system. Although economical to install, these systems have several major drawbacks: poor temperature distribution, greater temperature fluctuations, lower seasonal combustion efficiency and the possibility that gases from the flue may enter the greenhouse. Some growers have attached ductwork to the units to direct the warm air between the plant rows via large poly tubes. This greatly improves heat distribution. As well, they provide a direct source of outside air to the fire box, minimizing the possibility of incomplete combustion.

Cooling

Greenhouses require a great deal of heat to maintain temperatures during the winter. In the warmer months, however, it is necessary to reduce temperatures. Cooling is normally accomplished by exchanging greenhouse air with outside air. One air exchange per minute is required for high-temperature summer conditions. The two systems commonly used are natural ventilation (peak ventilation for glass and acrylic houses and newer designs of double poly greenhouses; gutter ventilation for older double poly designs) and forced-air ventilation (fan-cooled greenhouses). With forced-air ventilation, additional summer cooling can be achieved by also installing a fan and pad system. Some growers use high-pressure fogging systems for both spring and summer cooling and for humidity control in the winter and spring.

Temperature Sensing and Control

In the past, growers relied on mechanical sensors to track greenhouse temperatures. Today, electronic sensors (thermistors) are now available that can be used in conjunction with analogue or digital controllers. These sensors should be placed near the growing point of the plant canopy and then raised as the plant grows to monitor the temperature immediately around the growing point.

Since temperatures often vary in different parts of the greenhouse, use an aspirated boxed sensor to draw greenhouse air across the thermometer and provide more accurate temperature readings.

When it comes to temperature and environmental control, the use of computers is now very common. Computers can be programmed to adjust or maintain temperatures based on the time of day, intensity of sunlight, relative humidity or many other factors. In addition to a static temperature set point, the computer allows for the ramping of temperatures from night to day (and vice versa). This controlled temperature increase or decrease enables growers to create an optimum temperature profile for plant growth, tailored to a selected cultivar or style of growing.

Computers require an extensive initial investment. However, the improved control over temperature, RH and greenhouse climate helps minimize disease incidence, making computers essential for all greenhouse sizes.

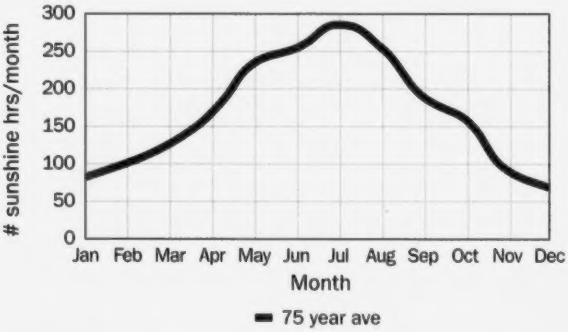
Light

Light is the most important factor in plant growth. Photosynthesis uses energy from the light to combine water and carbon dioxide, producing sugars.

However, light is also the factor over which growers have the least control. Artificial light can be used to stimulate photosynthesis, but the higher energy costs usually make it uneconomical to grow most vegetable crops this way, unless the increased levels of production and the price premium for out-of-season produce support it. However, using supplemental light is common in the growing of seedlings and transplants before planting out. In general, supplemental light at 40 W/m^2 over the desired photoperiod is adequate and economical. It will provide stronger, stockier plants in a shorter period of time during the short days and low light levels of December and January.

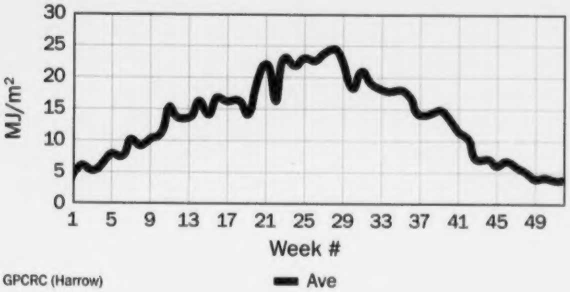
Normal sunlight patterns are presented in Figure 1–3, *Sunshine Hours — 75-Year Average*; Figure 1–4, *Global Radiation — Weekly Average* and Figure 1–5, *Global Radiation — 10-Year Average*. With relatively little light energy available for growth in mid-winter, it often takes twice as long to get the same amount of growth in January as in May. This must be considered when scheduling the production of greenhouse vegetable crops. Greenhouse management practices, including adjustments to seasonal and daily temperatures and nutrient levels, should be based on prevailing light conditions.

Figure 1–3. Sunshine Hours — 75-Year Average



GPCRC (Harrow)

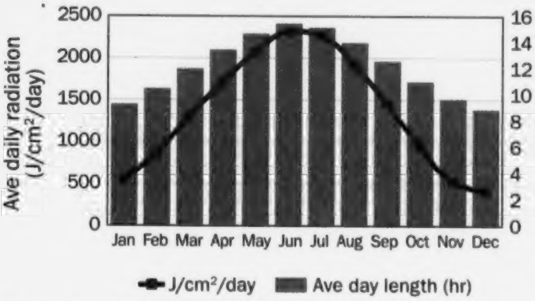
Figure 1–4. Global Radiation* — Weekly Average



GPCRC (Harrow)

* *Global radiation is the measure of solar energy between 200 and 2,800 nanometres.*

Figure 1–5. Global Radiation — 10-Year Average



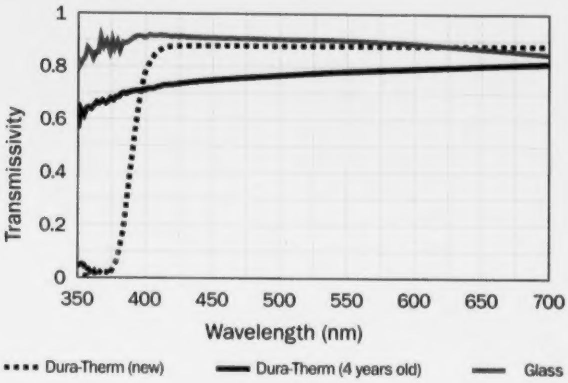
Vineland Research Station (Vineland Station)

Interaction Between Light Intensity and Plant Leaf

Leaf size is related to light intensity. This is particularly true for young, expanding leaves: during periods of low light intensity they tend to grow larger, allowing more light to be intercepted and thus improving the overall energy conversion efficiency of the plant. These large leaves are usually thin, have a thinner cuticle layer and are more easily damaged when handled during normal cultural practices. In contrast, leaves grown under high light intensity usually have a thicker cuticle.

In leaves formed under low light conditions, the chloroplasts are aligned perpendicular to the sun radiation. In this configuration they are able to capture more light energy. However, the degree of response depends on the age of the plant, the age of the leaves and the length of time spent acclimatizing. This explains, in part, why spring-grown plants are bigger than fall-grown plants, even though the light levels may be the same.

Figure 1–6. Comparison of Light Transmission Between Glass and Double Polyethylene



Light Transmission

Glazing material greatly affects the amount of light that penetrates the greenhouse. Traditionally, vegetable greenhouses used glass. However, for the past 20 years double poly greenhouse structures have become increasingly popular, combining energy conservation and low capital construction costs without loss of productivity (see Figure 1–6, *Comparison of Light Transmission Between Glass and Double Polyethylene*).

Two major factors determine how much light is transmitted through a glazing material: the refractive index and the amount of light absorbed by the material itself. Theoretical calculations show that glass reflects about 4% of the light at each glazing/air interface. This means that the maximum light transmission for a single layer of material is about 92%. In contrast, the maximum theoretical transmission through a double layer of glass is 84% (2 layers with 4% at each surface interchange = 16%), indicating that the major loss of light is through reflection, not absorption. This explains why light transmission through a double layer of glazing material is considerably less than through a single layer of the same material with a total thickness equal to the double layer.

Unlike glass, there is relatively small difference in light transmission between 100 and 150 micron polyethylene films. In addition, research and development in additives for polyethylene film production has increased the light transmission properties of the newer plastics, improving the level and quality of light reaching the plants. This has also allowed for adjustments of ultraviolet (UV) transmission to decrease disease incidence (since research shows that certain UV wavelengths increase the incidence of *Botrytis*) and allow bumblebees to perform in double polyethylene greenhouses.

Keep in mind, however, that many conflicting reports have been published on the light transmission of different materials. Different measuring techniques usually account for these discrepancies. In general, only 60–75% of light striking the outer surface of the greenhouse actually reaches the plant.

Current roof designs and increased gutter height of greenhouses have improved light transmission, made management of the greenhouse environment easier and improved growing conditions *(Plates 4, 5).*

Note that different equipment and control systems may use different units to measure light intensity. It is often expressed in radiation terms as watts per metre squared (W/m^2) or joules per metre squared (J/m^2). Photometrically, light intensity is expressed in lux or foot-candles. Table 1–1, *Conversion Table for Light* shows the factors used to convert between these different light measurements.

The most useful light for photosynthesis is known as photosynthetically active radiation (PAR), which is light in the 400–700 nm wavelengths.

Relative Humidity (RH)

Relative humidity is the ratio of the actual amount of water vapour present in a given amount of air (the absolute humidity) to the maximum amount of water vapour that can be held within that volume of air at a given temperature. RH is expressed as a percentage and varies between 40% and 100% in most greenhouses. The higher the relative humidity, the more water is present in the air (see Table 1–2, *Water Content of Air at 18°C for Various Humidities*). Wet bulb and dry bulb readings, together with psychometric charts, provide information about the amount of water present in the air, the relative humidity and the dew point. Most computer systems for controlling greenhouse environments automatically provide this information.

The amount of water vapour that air can contain increases with temperature, almost doubling for every 10°C increase in temperature, as illustrated in Table 1–3, *Effect of Temperature on the Saturated Water Content of Air.* This means that the amount of water in the air required to achieve 70% RH varies with temperature, as illustrated in Table 1–4, *Vapour Pressure Relations.* For example, at 20°C and 70% RH,

Table 1–1. Conversion Table for Light

Light Source	W/m^2 to µmol/m^2/sec	µmol/m^2/sec to W/m^2	lux to µmol/m^2/sec	µmol/m^2/sec to lux	lux to W/m^2
Sunlight	4.57	0.22	0.02	54.00	0.004
High-pressure sodium (SON/T)	4.98	0.20	0.01	82.00	0.002
Incandescent	5.00	0.20	0.02	50.00	0.004
High-pressure mercury	4.52	0.22	0.01	84.00	0.003
Metal halide	4.59	0.22	0.01	71.00	0.003

W/m^2 = watts/square metre
µmol/m^2/sec = micromols/square metre/second

Source: Thimijan and Heins, 1985. HortScience *18: 818-822.*

the air can hold only 12.2 g/m^3 water. But at 30°C and 70% RH, it can hold 21.9 g/m^3 water. This difference affects transpiration and the drying capacity of air.

Table 1–2. Water Content of Air at 18°C for Various Humidities

Relative Humidity (%)	Water Content (g/m^3)
100	15.7
80	12.6
60	9.4
30	4.7

This table is derived from psychometric charts.

Source: 2001 ASHRAE Handbook—Fundamentals *(American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., 2001).*

Table 1–3. Effect of Temperature on the Saturated Water Content of Air

Temperature (°C)	Water Content (g/m^3)
0	4.9
10	9.5
20	17.8
30	31.8

This table is derived from psychometric charts.

Source: 2001 ASHRAE Handbook—Fundamentals *(American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., 2001).*

Table 1–4. Vapour Pressure Relations

Temp. (°C)	RH (%)	Max. Potential Water Content (g/m3)	Actual Water Content (g/m3)	Vapour Deficit (g/m^3)
20	70	17.6	12.2	5.4
25	70	23.6	16.4	7.2
30	70	31.7	21.9	9.8

This table is derived from psychometric charts.

Source: 2001 ASHRAE Handbook—Fundamentals *(American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., 2001).*

Vapour Deficit or Vapour Pressure Deficit

The amount of water vapour present in the air exerts pressure, which is expressed in millibars (mbar) or kiloPascals (kPa). Water vapour present in the leaf also exerts pressure. The difference between these two values is the vapour deficit or vapour pressure deficit (VPD). The greater the VPD, the greater the transpirational pull (water movement from the leaf into the atmosphere that occurs through open stomata).

A simple method to calculate VPD is as follows:

1. Determine the vapour pressure in the leaf:
   - Measure the leaf temperature.
   - Look up the vapour pressure at 100% RH using a psychometric chart. (Since the interior of a healthy leaf is always moist, its RH is assumed to be 100%.)
2. Determine the vapour pressure in the air:
   - Measure the air temperature and the humidity.
   - Use these to look up the vapour pressure using a psychometric chart.
3. Subtract the vapour pressure of the air from the vapour pressure of the leaf.

As Table 1–4 illustrates, vapour deficit increases with temperature. The lower vapour deficit at 20°C means the transpirational pull is not as high as at the higher vapour deficit of 30°C.

Plant vigour and growth rate can be altered by adjusting the VPD. A VPD that is too low results in low transpiration; thicker, larger leaves; thick stems; weaker root systems; and plants that are more prone to disease infestations. A VPD that is too high results in a high transpiration rate; thinner, smaller leaves; thinner stems; and a stronger root system. Extreme VPD values or rapid increases or decreases in VPD are detrimental to plant growth, fruit quality and plant productivity.

Table 1–5, *The Relationship of VPD to Temperature and RH*, page 8, shows the VPD values at various temperature and RH values. The optimal VPD is 0.4–0.8 kPa (4–8 mbar), indicated by the unshaded areas on the chart. At these VPD values, optimal transpiration rate and nutrient uptake, coupled with adequate sugars, result in healthy, vigorous, high-yielding plants.

The VPD can be adjusted in the greenhouse by altering greenhouse air temperatures, venting rates and air movement. Changing how much water is available to the crop also alters the VPD.

If the greenhouse air is heated without changing the actual amount of moisture present, the relative humidity will decrease. Conversely, cooling the greenhouse will increase the RH. Where different day and night temperature regimes are established, relative humidity will change accordingly. For instance, many growers increase the temperature at sunrise by about 3°C, thus lowering the relative humidity by 12–18% and increasing the transpiration rate. In the evening, the drop in temperature increases the relative humidity, requiring some ventilation to remove moisture and prevent disease development.

A rule of thumb for most greenhouse conditions is that for each degree Celsius increase in temperature, the relative humidity drops about 4–6%.

When moist air reaches the saturation point, condensation occurs on the cooler surfaces in the greenhouse. During the day, leaves are usually warmer than the surrounding air. At night, the leaf temperature may drop 1°C or 2°C below ambient air temperature due to radiant heat loss. If the greenhouse RH is near 95%, condensation may take place on leaf surfaces. Prolonged periods of high relative humidity and free water encourage bacterial diseases and the germination of many fungal spores, such as *Botrytis* or powdery mildew.

Table 1–5. The Relationship of VPD (mbars) to Temperature and RH

TEMP (°C)	RH (%)									
	50	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**
15.0	8.5	7.7	6.8	6.0	5.1	4.3	3.4	2.6	1.7	0.9
16.0	9.1	8.2	7.3	6.4	5.5	4.6	3.6	2.7	1.8	0.9
17.0	9.7	8.7	7.8	6.8	5.8	4.8	3.9	2.9	1.9	1.0
18.0	10.3	9.3	8.3	7.2	6.2	5.2	4.1	3.1	2.1	1.0
19.0	11.0	9.9	8.8	7.7	6.6	5.5	4.4	3.3	2.2	1.1
20.0	11.7	10.5	9.4	8.2	7.0	5.9	4.7	3.5	2.3	1.2
21.0	12.4	11.2	9.9	8.7	7.5	6.2	5.0	3.7	2.5	1.2
22.0	13.2	11.9	10.6	9.3	7.9	6.6	5.3	4.0	2.6	1.3
23.0	14.1	12.6	11.2	9.8	8.4	7.0	5.6	4.2	2.8	1.4
24.0	14.9	13.4	11.9	10.4	9.0	7.5	6.0	4.5	3.0	1.5
25.0	15.8	14.3	12.7	11.1	9.5	7.9	6.3	4.8	3.2	1.6
26.0	16.8	15.1	13.4	11.8	10.1	8.4	6.7	5.0	3.4	1.7
27.0	—	—	—	12.5	10.7	8.9	7.1	5.4	3.6	1.8
28.0	—	—	—	13.2	11.3	9.5	7.6	5.7	3.8	1.9
29.0	—	—	—	—	12.0	10.0	8.0	6.0	4.0	2.0
30.0	—	—	—	—	12.7	10.6	8.5	6.4	4.2	2.1

Note 1: The unshaded area is the optimum range for most greenhouse crops
Note 2: 1 mbar = 0.1 kPa
Note 3: As a general rule the following expressions are interchangeable: 0.1 kPa = 0.7 g/m^3 *= 3% RH*

Source: W.R. Jarvis, Managing Diseases in Greenhouse Crops.

An extremely low RH may occur when large amounts of dry air enter the greenhouse on a bright, sunny day during the early part of the year. The cooling cycle must be monitored closely during this period. Too much ventilation reduces RH too rapidly and may cause burning of tender foliage or curling of young cucumber fruit, decreasing fruit quality and yield.

Misting or fogging systems that maintain RH can be installed to prevent damage to specific crops. During the summer, when forced ventilation is needed, a high daytime RH is often not a problem, unless a fan and pad system has been installed for cooling. However, ventilation and/or heating are often required at night to prevent excessively high RH and condensation on the foliage.

Note that relative humidity affects pollen transfer. For tomato pollination to occur, RH must be between 70–75%. This permits the proper release of pollen from the anthers onto the stigma. After pollination, a higher RH helps the pollen to germinate, improving fertilization and increasing fruit size.

Carbon Dioxide (CO_2)

The ambient CO_2 level of outside air is about 360 parts per million (ppm) on a volume basis. During photosynthesis, plants use energy from the sun to absorb CO_2 from the air and combine it with water to produce carbohydrates necessary for plant growth. This means that if an airtight greenhouse is not adequately vented, the CO_2 level can drop well below the outside level, especially during sunny periods, when plants are photosynthesizing. CO_2 concentrations as low as 200 ppm have been observed in greenhouses during periods of bright sunlight, even with summertime ventilation. If supplemental CO_2 is not added, photosynthetic activity will decrease, lowering plant growth and fruit yield.

The amount of supplemental CO_2 is specific for each operation. When CO_2 levels are increased to 800–1,300 ppm during the day, plant growth increases 15–20% and fruit size, quality and colour improve. The optimum level of supplementation depends on the crop and the amount of air movement within the greenhouse. In general, the optimum CO_2 level with good air circulation is around 1,000 ppm on sunny days and 400 ppm on cloudy days or when vents are opened more than 10%. In Ontario, most greenhouse growers with year-round operations add CO_2 into their greenhouses, monitored with CO_2 controllers to maintain set points.

Keep in mind that the potential increase in yield must be balanced against the increased cost and the market prices that growers can command. In Ontario, it is generally economical to supplement CO_2 in the summer months, as well as any time the vents are open more than 10%. Liquid CO_2 and flue gas CO_2 lend themselves well for summer CO_2 supplementation.

Methods to Increase CO_2

The most common method of increasing CO_2 levels is by burning fuels such as natural gas, propane or low-sulphur kerosene. These fuels are burned in special units positioned at appropriate locations in the greenhouse to improve distribution. Flue gas CO_2 from the heating plant/boiler system is an alternative source for supplementing CO_2, while the heat generated is stored as hot water in large buffer tanks for use at night. Another possibility is liquid CO_2. In recent years this has become popular and, with increased use, more economical.

The rate of supplemental CO_2 depends on the infiltration rate of outside air into the greenhouse. As a rule, a CO_2 supplementation rate of 45–65 kg/ha/hr maintains 1,000 ppm in a closed greenhouse or 350–400 ppm in a vented greenhouse. For burner capacity or the rate of supplemental liquid CO_2 for different types of greenhouses, see OMAFRA Factsheet *Carbon Dioxide in Greenhouses*, Order No. 00-077. This factsheet also deals with CO_2 distribution and cost, as well as the dangers of incomplete combustion.

Energy Conservation

Energy is one the biggest expenses in greenhouse vegetable production. The judicious use of energy conservation technology is recommended for commercial greenhouses. However, the impact of this technology on crop production must be considered. Simply maintaining a lower 24-hour temperature is not advisable, since it decreases plant development, leads to lower fruit quality and increases the incidence of disease. Instead, it is better to optimize the conditions for maximum economic yield.

Energy-saving double poly greenhouses and/or double-walled, SDP/acrylic side walls are common in Ontario. Management and cultural practices have changed to compensate for the lower light transmission and the lower rate of air exchange per hour of these greenhouses without reducing crop production. (Natural air exchange in a glass house is 0.75–1.5 exchanges/hour, while double poly greenhouses have 0.2–1.0 exchanges/hour.) Keep in mind that newer greenhouses (both double poly and glass ones) have significantly less infiltration loss than older ones: 0.5–1 air exchanges/hour compared to 1–4 air exchanges/hour.

New developments in greenhouse polyethylene films have improved energy savings. Infrared (IR) films and anti-condensate films are an example. The IR films decrease heat loss from the greenhouse, while anti-condensate films reduce the need for venting to manage the greenhouse environment. As well, there is little accumulation of water film on the inside roof surface with anti-condensate films, so light transmission is increased.

Other energy conservation techniques to implement include:

- insulation of heating pipes to reduce heat loss along the mainline and headers during transportation from the boiler room
- side wall insulation — insulate at least 0.6 m below grade
- wind breaks — sheltering the greenhouse from prevailing winds will decrease infiltration losses
- heating system tune-ups that include regular boiler maintenance
- heat placement — locate heat pipes close to plants to decrease losses to greenhouse surfaces and locate grow pipes (small-diameter hot-water heating pipes) within the crop canopy to improve plant productivity/quality
- delay planting — plant when heating requirements are not as high, but keep in mind that early crops tend to command a higher market price

While shade/energy curtains are not common in double polyethylene greenhouses in Ontario, some newer greenhouses are now using them. Modern glass greenhouses use energy curtains routinely.

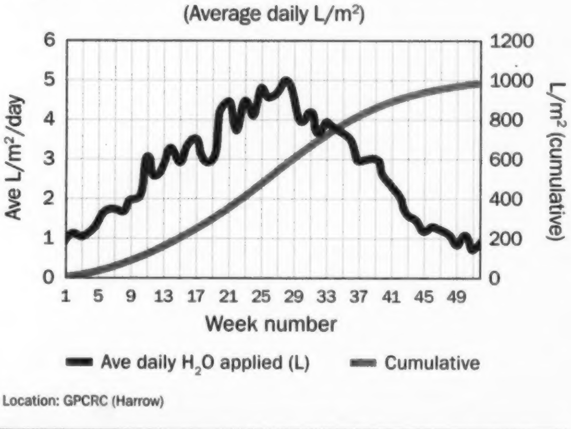
A temporary 2 mil clear polyethylene sheet placed over the crop wires to seal the greenhouse when the crop is started during the months of December and February can decrease energy loss and improve humidity in the greenhouse. The screen is removed once the plants' respiration rate releases excess moisture into the greenhouse.

For information about green energy on the farm, see OMAFRA's website *The Green Energy Business Information Bundle for Farmers* (www.ontario.ca/greenfarming). It has information about green energy on the farm, including ways to both save energy and generate energy. More information on energy conservation and efficiency can be found on the AgEnergy Services website at www.agenergyservices.ca/.

Water

Water supply and water quality are very important for greenhouse crop production. Select a site with an ample supply of high-quality water. To meet the needs of a fully grown crop, the irrigation system must be able to deliver at least 8 L/m²/day. Some fully grown greenhouse crops (e.g., cucumbers) may require up to 5 L of water/plant/day during the sunny summer months (Figure 1–7, *Water Application in Greenhouse Vegetables*).

Figure 1–7. Water Application in Greenhouse Vegetables



Location: GPCRC (Harrow)

Most greenhouse vegetable operations in southwestern Ontario use municipal water from the Great Lakes. Other operations rely on well water or rainfall collected in cisterns or ponds. Remember, more water is used in year-round greenhouse production than can be collected from the roof of a greenhouse range, so an additional water source is required. Rivers or streams are not recommended as the only source of water because there is a high risk that contaminants could damage the greenhouse crop.

In most areas, municipal water is of adequate quality, with soluble salts of less than 0.750 milliSiemens per centimetre (mS/cm).[1] Conduct water tests if well water is used, since it may be of very poor quality and unsuitable for continuous irrigation. Contact OMAFRA's greenhouse vegetable specialist for advice.

Generally, water quality for greenhouse use may be divided into three classes (see Table 1–6, *Classification of Water Quality*).

Table 1–6. Classification of Water Quality

Class	Electrical Conductivity (mS/cm)[1]	Sodium (ppm)	Chloride (ppm)	Sulphate (ppm)
1	0.5	<30	<50	<100
2	0.5–1	30–60	50–100	100–200
3	1.0–1.5	60–90	100–150	200–300

[1] 1 mS/cm = 1 mmhos/cm or 1,000 µS/cm = 1,000 µmhos/cm

Note 1: This table is a guideline to assess the water quality for use in greenhouse vegetable production.

Note 2: Chloride-sensitive crops (e.g., cucumbers) should be grown only in Class 1 water.

Note 3: Sodium and chloride are normally found in the ratios presented in this table. If sodium levels are in the 30–60 ppm range, for example, chloride levels will likely fall in the range of 50–100 ppm. If this is not the case, the class of water is based on the level of the more concentrated ion.

Water quality of Class 1 is good for all irrigation purposes. Most water obtained from Lakes Erie and Ontario falls within this category.

Water in Class 2 should only be used in substrate and soil culture if adequate leaching can take place. It is unsuitable for nutrient film technique (NFT) and for salt-sensitive crops grown in sub-irrigation systems.

Class 3 is not recommended for salt-sensitive crops (e.g., cucumber) or crops grown in a limited root volume or in recirculating systems. If the salt level (measured by electrical conductivity) exceeds 1.5 mS/cm, it is considered marginally suitable for greenhouse irrigation. In some cases crops can be grown, but yields may be reduced as a result. The toxic concentration for sodium (Na+) is lower than that for chlorides (Cl–). It may interfere with the uptake of potassium, calcium and magnesium. Some crops (e.g., cucumber) are chloride sensitive. Note that for most areas in Ontario, sodium levels are low in well water, while sulphates can be relatively high due to the presence of gypsum in the aquifers. Most crops do not require more than 100 ppm of sulphates (33 ppm elemental sulphur) to meet their nutritional requirement for sulphur.

The quality of irrigation water is more important in hydroponic/soilless culture than in soil. Always consider water quality when establishing a fertilization program. For example, if the water contains large amounts of calcium or magnesium, reduce the rates of calcium nitrate and magnesium sulphate accordingly. Any nitrogen lost because of these adjustments can be made up by increasing the amount of another nitrogen-containing fertilizer. Note that certain elements such as iron, zinc and manganese can be high in some water supplies.

To create fertilization schedules for greenhouse vegetable crops, use water with sodium levels below 50 ppm and chloride levels below 70 ppm. If the water contains more than 100 ppm sodium or 140 ppm chloride, find alternative water sources or use a water purification system such as reverse osmosis. Tomato crops may be grown in a nutrient solution containing 100 ppm chloride without too much difficulty. However, it is best to select a water source that is low in these two elements.

If rainwater is used, the level of bicarbonate will likely be too low. To raise it, add potassium bicarbonate to the water (not to the stock solutions). If the bicarbonate in the water supply is higher than 60 ppm, add phosphoric and/or nitric acids to achieve the desired pH (5.5–5.8).

Nutrient Solution Recycling

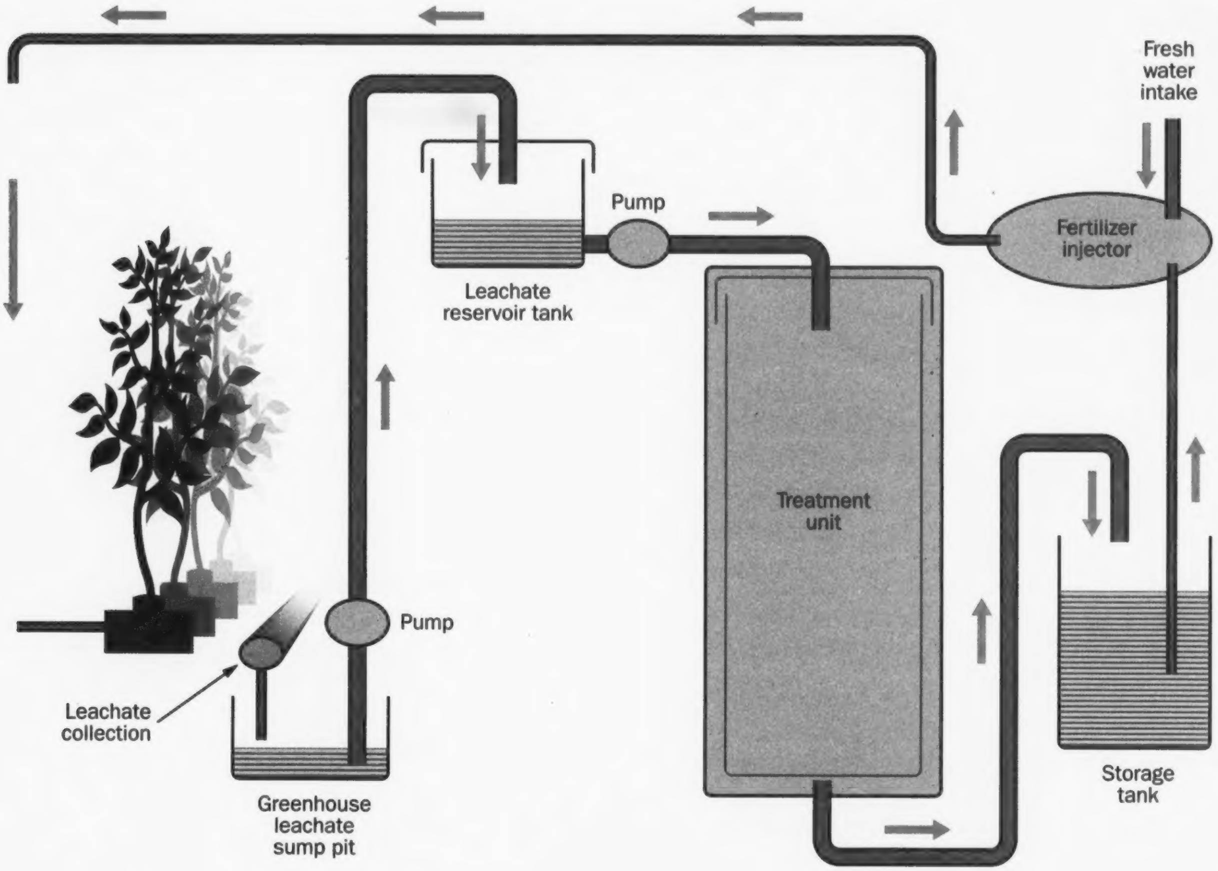
Nutrient solution recycling reduces the water use in a greenhouse operation by 25–30% and decreases the use of fertilizer 30–40%. The limitation of implementing nutrient solution recycling is the potential for disease transfer via the recirculated solution. This can be addressed with a disinfection system.

Nutrient Solution Disinfection

There are several systems for disinfecting nutrient solutions available that decrease the level of pathogens present either by a physical process (e.g., filtration) or by killing the pathogen (e.g., heat). Factors determining which system to select include:

- the amount of space available to place the equipment
- the degree of disinfection desired (some growers may want a completely disinfected nutrient solution, while others aim for a nutrient solution that contains a certain amount of bioactivity)
- the initial investment and running cost
- ease of maintenance

Figure 1–8. Nutrient Solution Recycling Layout


Fresh water intake
Leachate reservoir tank
Pump
Fertilizer injector
Treatment unit
Pump
Leachate collection
Greenhouse leachate sump pit
Storage tank

A basic setup (Figure 1–8, *Nutrient Solution Recycling Layout*) requires a collection system in the greenhouse that transfers the solution to a central reservoir tank. The solution then passes through a treatment system into another reservoir tank before being blended with fresh water and reapplied to the crop. The nutrient solution tanks may be above ground *(Plate 6)* or below ground *(Plate 7)*.

Slow Sand Filtration

These systems are relatively inexpensive to install and operate, and they are easy to run. They are generally used in smaller operations but can be scaled up as needed.

The size of the sand grains used and the flow rate determine the size of the unit and how well it works. A smaller grain size provides more effective filtration but slows down the rate of filtration. Too large a grain size increases flow rate but means the filtration may be less effective.

A 1.0-ha greenhouse operation requires a filtration area of 25 m^2 if the flow rate is 0.1 $m^3/hr/m^2$, while a faster flow rate requires less filtration area — a flow rate 0.3$m^3/hr/m^2$, for example, requires a filtration area of only 8.3 m^2. The standard height of the filtration tank is 2.54 m.

This system works because microbes adhere to the sand particles, and there is natural suppression by the microflora. A slow sand filtration system requires regular maintenance. When the rate of flow through the filter decreases, the top few centimeters of sand must be removed and fresh sand added to maintain the correct height of the sand layer.

Lava Rock Filtration

The general setup of a lava rock filtration system is similar to slow sand filtration, except small lava rocks are placed in the filter rather than sand and air is bubbled into the system *(Plate 8)*, keeping the lava rocks in motion and aerating the solution. Lava rock filtration maintains the biological balance in the water and has low maintenance and operating costs. These units are smaller than sand filters and are able to treat a larger volume of water at a faster rate. Contact the supplier for information regarding the flow rate and the size of the unit required to treat a specific volume of water.

Heat Treatment

This system is designed to raise the temperature of the nutrient solution to 90°C for 30 seconds (or 85°C for 3 minutes). *Plate 9* is an example of a commercial-scale heat treatment unit. After heat treatment the solution is cooled by using it to preheat the incoming water in a heat exchanger. After cooling, the temperature of the outgoing treated water remains 3–5°C higher than the temperature of the incoming water. The excess heat in the treated nutrient solution can be a problem in the summer, since the nutrient solution may be too warm to be applied to the crop. On some summer days the temperature of the nutrient solution coming from the greenhouse can be as high as 25–28°C. Blend this warm nutrient solution with cool well water (<15°C) to cool the solution before reapplying it to the crop. Lower the pH of the nutrient solution to pH 4.0 to minimize the deposition of salts in the heat exchanger, and compensate for any additional nutrients provided by the added acid. A key advantage of this system is that temperature and exposure time can be monitored and recorded via computers, where the information can be readily reviewed.

Ozonation

Ozone (O_3) is a free radical consisting of three oxygen molecules. It is very reactive, with 10 times more oxidation potential than chlorine. Ozone is generated on site by moving air through a high-energy electrical field, a process that requires 8–17 kWh per kilogram of O_3 generated *(Plate 10)*. The effectiveness of ozone disinfection is determined by dose, time and flow rate. A rate of 10 g ozone for 1 hour per cubic metre of water is usually effective. Low rates result in ineffective disinfection, while excessive rates may cause damage to the roots and the crop. Ozone in the nutrient solution will cause manganese (Mn) and iron (Fe) to precipitate out of the solution, making them unavailable to the plant. Micronutrient levels in the nutrient solution should be increased accordingly.

Ultraviolet (UV) Treatment

Ultraviolet systems have been used in the greenhouse sector for many years, especially in NFT growing systems. The nutrient solution is passed over the UV light bulb, which emits UV-C (254 nm wavelength) light. The bulb is enclosed in a chamber that allows a thin film of solution to flow over the bulb, ensuring good UV penetration *(Plate 11)*. UV does not penetrate too far into the water and is easily reflected or absorbed by materials in the solution. It is therefore important to pre-filter the solution using a sand filter and a 100-mesh inline filter to reduce turbidity caused by plant debris and particles. Normal UV use will cause an organic film to form on the bulb and iron in the nutrient solution to precipitate onto the light bulb. Since both these effects reduce the bulb's efficacy, it must be regularly cleaned. Modern systems perform this automatically, triggered by sensors that detect the loss in UV emission from the bulb, as well as a drop in transmission through the solution. The bulb is soaked in a low pH solution and a wiper is passed over the bulb. This solution then is released and the bulb is rinsed before the next nutrient solution treatment.

The ratio of dose to flow rate is critical: 100 mJ/cm^2 of UV light is required to kill most fungi, while 250 mJ/cm^2 will provide complete disinfection.

2. Analytic Testing

Since hydroponic systems have a relatively low buffer capacity, all nutrients applied to the media are generally available to the crop. This means that growers using hydroponic production systems for greenhouse vegetables must use precision in applying fertilizers to their crops. Fortunately, any errors in fertilization will show up relatively quickly in the plants. Likewise, the plants will respond rapidly when the errors are corrected.

While growers can use on-site colormetric kits and single-element testing units to check some macronutrients more regularly, laboratory tests are more accurate and convenient. A list of laboratories that perform greenhouse media and nutrient solution analysis is provided in Appendix D, *Soil Testing Labs in Ontario.*

Nutrient Solution and Analyses

Conducting frequent and regular nutrient solution analyses lets growers detect trends in nutrient levels before problems arise. For soilless culture (rockwool, coco coir, etc.), analyze the following every 7–14 days to make sure the correct fertilizer is applied and to determine what adjustments are needed to compensate for plant consumption and weather conditions:

- feed solution (solution applied to the crop)
- root zone solution (solution extracted from the bag)
- leachate (captured solution leaching from the bag)

This becomes more crucial when nutrient solutions are recycled. It is also important to monitor changes in ions such as sodium and chloride that are not necessary for plant growth, since these nutrients tend to accumulate in the nutrient solution, slowing plant growth.

Weekly analysis of the Nutrient Film Technique (NFT) solution from the reservoir provides similar information. Each test should include an analysis of both macronutrients and micronutrients.

Tissue/Foliar Testing

These tests provide information regarding the nutrient status of the crop. Regular testing reveals trends that allow growers to implement corrective measures before problems arise. At least once a month, conduct a foliar analysis.

Each crop has a specific leaf used for analysis:

- tomatoes — the 5th leaf from the growing tip on the main stem
- cucumbers — the 3rd leaf from the growing tip or from a lateral near the upper part of the crop canopy once topping has occurred (the leaf should be approximately 10 cm across to provide enough material for testing)
- peppers — a young, fully expanded leaf about 15 cm from the growing tip
- lettuce — a mature leaf

Wrap leaf samples from several different plants in a paper towel, place them in a plastic bag, seal the bag and place it in a standard brown envelope. Mail the sample or ship it by courier to the lab.

Table 2–1, *A Guide to Nutrient Content of Leaf Tissue,* page 16 provides a guide to the normal acceptable nutrient ranges for greenhouse vegetables.

Soil Testing

In soil-grown greenhouse vegetable crops, conduct soil testing prior to planting to determine both the pre-plant and post-plant fertility program. Regular soil and tissue testing during the season is essential to ensure crops have received enough fertilizer.

During the growing season, a regular soil analysis every 2 weeks helps maintain the ideal fertility program. Soil samples should represent the soil type in the greenhouse. Using a soil probe, take samples from several locations in the greenhouse to a depth of 20 cm. Mix these samples together, and forward this mixture to the lab for analysis. Keep samples separate if there are different soil types or if a specific problem area exists. This allows for specific fertilizer programs for these locations.

Table 2–2, *Guidelines for Greenhouse Growing Media Analyzed by the Saturated Media Extract (SME) Method* outlines acceptable nutrient levels in the soil and serves as a guide for subsequently adjusting the fertility program.

Table 2–1. A Guide to Nutrient Content of Leaf Tissue

	Tomatoes	**Cucumbers**	**Peppers**	**Lettuce**
Major Elements (%)				
Nitrogen	4.0–5.5	4.0–6.0	3.5–5.5	4.0–5.0
Phosphorus	0.3–0.65	0.6–1.0	0.4	0.6–0.8
Potassium	3.5–5.0	3.5–4.0	5.0–5.9	7.8–13.6
Calcium	1.6–3.2	2.4–3.2	2.8–3.2	0.8–1.2
Magnesium	0.36–0.5	0.36–0.5	0.5–0.75	0.25–0.5
Sulphur	1.3	0.3	0.5	0.3
Minor Elements (ppm)				
Manganese	55–165	55–165	55	55–110
Copper	5–10	7–12	5–10	6–15
Zinc	30–50	40–60	30–60	30–40
Boron	55–75	55–75	55–75	40–50
Iron	85–110	85–110	112	85–110

Source: The information in this table is historical data developed over time by Agriculture and Agri-Food Canada (AAFC) and Ontario Ministry of Agriculture Food and Rural Affairs (OMAFRA) staff at the Greenhouse and Processing Crops Research Centre, Harrow, and by OMAFRA staff at Vineland Research Station, Vineland Station.

Table 2–2. Guidelines for Greenhouse Growing Media Analyzed by the Saturated Media Extract (SME) Method*

Analysis	**Low**	**Acceptable**	**Optimum**	**High**	**Very High**
Soluble salt (mS/cm)	0–0.75	0.75–2.0	2.0–3.5	3.5–5.0	5.0+
Nitrate-N (ppm)	0–39	40–99	100–199	200–299	300+
Phosphorus (ppm)	0–2	3–5	6–10	11–18	19+
Potassium (ppm)	0–59	60–149	150–249	250–349	350+
Calcium (ppm)	0–79	80–199	200+	—	—
Magnesium (ppm)	0–29	30–69	70+	—	—

Source: The information in this table is historical data developed over time by Agriculture and Agri-Food Canada (AAFC) and Ontario Ministry of Agriculture Food and Rural Affairs (OMAFRA) staff at the Greenhouse and Processing Crops Research Centre, Harrow, and by OMAFRA staff at Vineland Research Station, Vineland Station.

**This technique involves creating a paste with a soil sample and distilled water. The filtrate is then analyzed for nutrients.*

3. Growing Media

The growing media must provide four basic needs for the plant: water, nutrients, oxygen and support for the roots. In recent years, most Ontario greenhouse vegetable growers have shifted from soil culture to hydroponic/soilless culture. Today, most greenhouse vegetables are grown in rockwool (55%) and coir (coco coir) (35%). The remaining 10% are grown in other media such as Nutrient Film Technique (NFT), foam, expanded clay pellets, peat, sawdust and soil. The hydroponic/soilless media normally do not supply any nutrients for plant growth, so these must be provided in the fertilizer solution. This application of fertilizer and water through an irrigation system is called fertigation.

Rockwool Culture

Rockwool is an artificial growing media made from basaltic rock, coke and limestone. The basaltic rock is melted in a kiln and then spun in threads that are layered to form mats. These are used to insulate buildings and pipes and to provide a growing medium for horticultural purposes. Horticultural rockwool is manufactured under strict guidelines to create a uniform product of specific density and treated with a wetting agent. It is cut to standard sizes and then wrapped and sealed in polyethylene bags.

Horticultural rockwool:

- is sterile (free of pathogens, weed seeds, etc.)
- has a low cation-exchange capacity or is inert and therefore does not interact with the nutrient solution
- has a high water-holding capacity
- usually has a high initial pH
- is lightweight and easy to handle
- allows for a shorter between-crop interval

Rockwool is a free-draining media. It is important to lay out the production system to ensure uniform watering of all plants. If the system is not well designed (if the slope of the greenhouse floor is uneven, for example), some bags may remain too wet, restricting plant growth and causing lack of uniformity in the crop, or remain too dry, again restricting plant growth and fruit production.

A basic rockwool production system consists of:

- a groundsheet that isolates the soil surface from the greenhouse growing environment
- a raised trough system (with an integrated irrigation and leachate collection system)
- rockwool slabs that are placed on the troughs

If the system is set up directly on the ground, it should include:

- a groundsheet that isolates the soil surface from the greenhouse growing environment
- a styrofoam strip for insulation that is placed either above or below the groundsheet
- rockwool slabs that are placed on top of the styrofoam strip and groundsheet
- a drip irrigation delivery system
- a leachate collection system

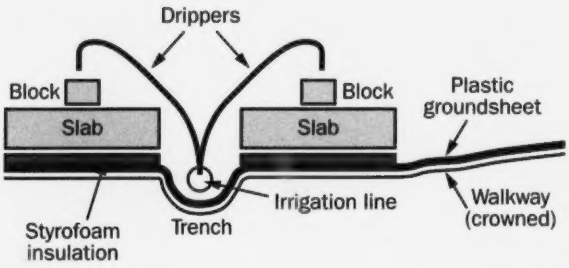
Rockwool is available as slabs, blocks, starting plugs and granules. The granules are used either on their own or as an additive to peat bag culture to form peat wool. Granule bag culture is not as popular as slab rockwool culture.

Seed is sown in the rockwool starting plugs and, after germination, transplanted into rockwool blocks. Once they have reached the desired size and stage, plants in the rockwool blocks are transplanted onto the rockwool slabs in the greenhouse. This process can take up to 6–8 weeks for tomatoes, 3–4 weeks for cucumbers and 7–9 weeks for peppers. This period is longer during winter and shorter in summer. There are two methods of setting up rockwool culture: open system or closed system.

Open System

In this system, the leachate solution is allowed to run to waste. The soil in each greenhouse is contoured to create a trench between the plant rows, with a slight crown along the length of the walkways. The site of the rockwool slab is level or on a slight slope (i.e., < 0.5%) towards the trench. The trench acts as a drain to collect the nutrient solution. Traditionally, a groundsheet is placed over the contoured soil and the drip irrigation system is then placed in the trench for convenience. See Figure 3–1, *Layout for Open-System Rockwool* for a diagram of the basic system.

Figure 3–1. Layout for Open-System Rockwool

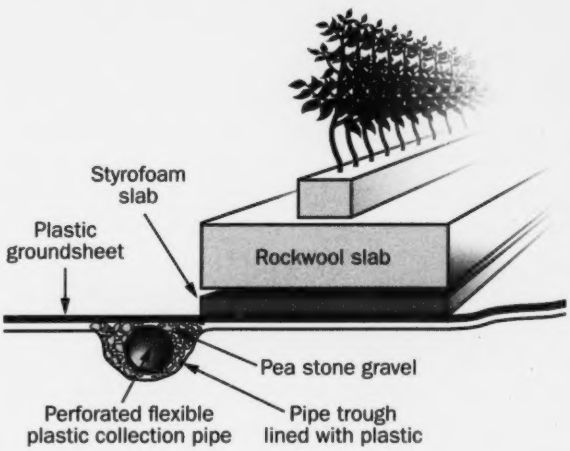


Closed System

In this system, the leachate solution is collected, treated and reused to irrigate the crop, improving the efficiency of fertilizer and water use (see *Nutrient Solution Recycling*, page 12). The basic setup is similar to the open system, but the drain trench is sloped at 0.5% towards one end of the greenhouse (Figure 3–2, *Layout for Closed-System Rockwool).* The base of the trench is lined with plastic. A perforated drainage tube is placed in the bottom of the trench, which is then backfilled with clean pea gravel up to ground level and covered with plastic groundsheet *(Plate 12).*

The size of the perforated drainage tube is determined by the size of the trench. In most cases, a 5-cm-diameter tube is sufficient to collect the leachate water and rapidly drain it. Rockwool slabs are placed beside the trench. At every drain hole for the slab, a slit is made in the groundsheet to allow the leachate to escape into the perforated drainage tube below.

Figure 3–2. Layout for Closed-System Rockwool


Styrofoam slab
Plastic groundsheet
Rockwool slab
Pea stone gravel
Perforated flexible plastic collection pipe
Pipe trough lined with plastic

The perforated drainage tube is connected to a 10-cm sewer pipe that drains to a reservoir, where the leachate is stored and treated before being re-used to irrigate the crop.

Numerous other techniques exist to capture leachate, including:

- flexible plastic sleeves with brackets to keep the rockwool slabs out of the leachate water
- styrofoam shaped to hold the slab with a deeper groove to channel the leachate water away
- preformed aluminum troughs with ridges in the base that channel the leachate
- preformed plastic troughs with leachate drainage channels formed at the base to allow the solution to be captured

Increasingly, growers are beginning to use the "V" system, where a single row of rockwool slabs with double the number of plants (compared to a normal twin-row system) is placed in the centre of the growing row. Alternate plants are trained to opposite sides of the growing row to form two plant rows. This decreases the amount of rockwool required to grow a crop, although it requires an irrigation system capable of delivering 150–200 mL/m^2/cycle every 15 minutes.

In both forms of rockwool culture, the rockwool slabs are placed in the greenhouse, the plant location is marked and a square hole is cut in the plastic overwrap. Hole size is determined by the size of the rockwool block used. The rockwool itself is left intact;

only the plastic bag is cut to expose the rockwool slab. Before transplanting the crop onto the rockwool slabs, a complete nutrient solution is applied to soak the bags thoroughly. The drip irrigation emitters are placed onto each hole and the irrigation is started.

Raised Trough System

The raised trough system is used in most new greenhouses, while many older facilities have been retrofitted to accommodate it *(Plate 13)*. In this system, rockwool slabs are placed in preformed raised troughs, 80–120 cm off the ground, either on stands or hung off chains from the trusses of greenhouses engineered to hold this load. The trough contains an integrated irrigation and leachate collection system.

The raised trough system lends itself to intercropping, where the new crop is planted as the old crop is coming to an end. The final harvest of the old crop coincides with the first harvest of the new crop.

Advantages

- Setup is faster during the construction phase, as there is no need to form the ground for leachate trenches.
- The greenhouse ground remains flat, making it easier to set up the pipe rail heating system or track system as well as perform greenhouse maintenance.
- The system is labour friendly, involving:
  - less bending
  - easier layout of growing media bags
  - easier planting
  - deleafing conducted at an easier working height
  - easier and faster harvesting
- Pest and diseases can be better managed because:
  - the base of the plants and lower stems and leaves can be more easily monitored for diseases
  - better air circulation improves the microclimate around the plant and minimizes the incidence of disease
  - dripper problems, such as blockages and leaks, are easier to detect and fix
  - biocontrols can be more easily introduced at the base of plants
- Water management in the growing media is easier because:
  - slabs are level, resulting in uniform wetness and draining
  - watering is more uniform, since all the emitters are uniformly placed and leaks and other problems are easily detected and repaired
  - the nutrient solution is easily collected for recirculation purposes
- Cleanup during the season (such as plant clipping) is easier, as is end-of season crop removal

Disadvantages

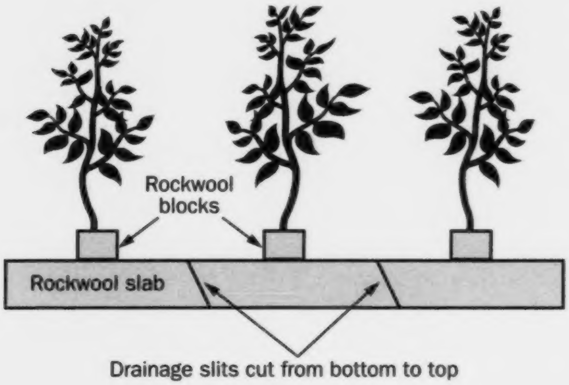
- The troughs are costly.
- The greenhouse structure must be designed to hold the weight of the troughs and plants.
- Algae can grow in the drain channel.
- There is less flexibility to alternate crops.

Water Management

Rockwool slabs, although free draining, can become waterlogged if short, frequent irrigation cycles are applied or if the drainage holes are not cut properly to allow free drainage. Drainage is especially critical during early plant growth stages and under low light conditions. Set the bags up so they are level and uniformly spaced, and make sure the drainage holes are cut cleanly, sized and located correctly for optimum drainage.

After the bags are placed in the greenhouse, they are saturated with a complete nutrient solution. (For specific solutions, see the discussion of individual crops in Chapters 5–9.) The bag must be completely saturated to activate the wetting agent, ensuring the whole slab is available to the plant roots. After planting, cut a slit in the bag from the bottom up to allow for drainage (see Figure 3–3, *Drainage Slits on Rockwool Slab for Tomato,* page 20). This is usually done 24–48 hours after planting. Water the plants for half an hour, and then apply water only on sunny days over the next 2–3 days. This ensures rapid root penetration into the slab and allows the slab to dry out. Apply the amount of water indicated in Chapters 5–9. Caution: Overwatering may result in excess vegetative growth and plants that are more susceptible to disease.

Figure 3–3. Drainage Slits on Rockwool Slab for Tomato



CAUTION: The final degree of slab dryness depends on the characteristics of the slab purchased. Follow manufacturers' recommendations.

Subsequently, the frequency and quantity of water applied to the crop is determined by several factors:

- the stage of plant growth
- light levels
- temperatures in the greenhouse and in the slab
- relative humidity or vapour pressure deficit in the greenhouse
- the amount of air movement

In general, 100 mL/cycle is used. This may vary depending on:

- the type of rockwool
- the stage of plant growth
- the time of year
- electrical conductivity (EC), a measure of the quantity of total dissolved salts or total ions present in the solution
- percentage drain

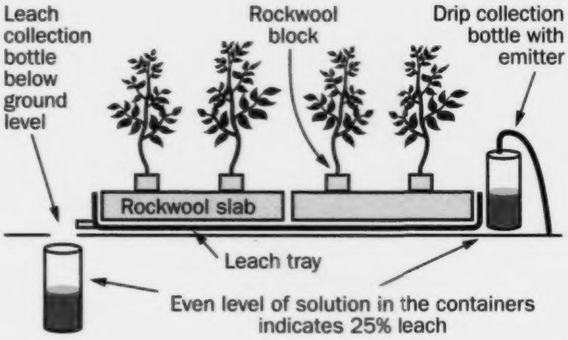
To determine the correct watering pattern, monitor both the EC in the slab and the percent drain/leachate. Use a large-bore hypodermic needle attached to a 50 cc plunger to extract the nutrient solution from the slab. Measure the EC using an EC meter or EC pen. (For information on optimal EC levels for specific crops, see Chapters 5–9.)

As well, monitor the percent leachate. Place 1 or 2 slabs in a tray with a drain and measure the amount of water that is collected over a 24-hour period. Take this measurement at the same time daily, usually before first watering. This allows the watering to be adjusted to obtain the proper root environment. Automatic leach counters are also available.

A leachate of 20–30% is generally recommended.

The simplest way to manually measure percent leachate is to use a 4-L graduated container to collect the solution applied from a single emitter. Use a similar container to collect the leachate from four plants irrigated by the emitter. Compare the volumes. If they are the same, the rate of leaching was 25% (Figure 3–4, *Leachate Measurement*). (Alternatively, collect the solution from 2 emitters and the leachate from 8 plants.)

Figure 3–4. Leachate Measurement


Leach collection bottle below ground level
Rockwool block
Drip collection bottle with emitter
Rockwool slab
Leach tray
Even level of solution in the containers indicates 25% leach

Keep a daily record of the amount of leachate and irrigated water, as well as the EC and pH of the irrigation water and the slab. This helps in determining the irrigation strategy to follow. If the EC is rising, it indicates that not enough water was applied based on the prevailing conditions for that day. Conversely, if the EC is decreasing, it indicates that too much water was applied.

Night watering is usually not recommended. Start the irrigation cycles 1–2 hours after sunrise and end them 1–2 hours before sunset. After the first irrigation cycle, check the slabs for leachate. If there is leachate after the first cycle, the slabs are too wet. Either delay the start-up time or end the irrigation earlier. If there is no leachate after the third cycle, the bags are too dry. In this case, extend the irrigation program later into the evening or start it earlier in the day.

An irrigation program that is not properly set up can decrease production and increase incidence of disease.

If the slabs are too wet, the result is:

- poor aeration of the slab
- softer, vegetative growth
- poor root growth
- increased risk of root disease

If the slabs are too dry, the result is:

- damaged root hairs
- high EC
- problems with calcium uptake and movement, leading to blossom end rot (BER) in tomatoes and peppers and leaf scorch/curl on young cucumber leaves
- harder growth and thinner plants
- smaller, darker, thicker leaves

To initiate and control the irrigation cycles, use either time, start tray, accumulated light radiation, water content meter or weigh scale or a combination of these.

The water content, EC and temperature of a rockwool slab may be measured using a unit available commercially. These units are portable and can measure data from several slabs at any time of day and night. The latest models are permanently installed and send recorded data directly to the irrigation computer, where adjustments to the irrigation schedule may be made.

Fertilizer Schedules

Most rockwool slabs tend to have a high pH when they are used for the first time. To compensate for this high pH, apply a nutrient solution with a pH of 5.0–5.5. It usually takes some time before the pH remains at the desired level of 5.8. Since the rockwool slab is inert, always apply a complete nutrient solution. For suggested fertilizer schedules, see the discussions of individual crops in Chapters 5–9.

Slab Sterilization

While rockwool slabs may be used for multiple crops, they should be sterilized between crops. Between 24 and 36 hours before the crop is terminated, decrease the amount of water applied and allow the plants to draw all the water from the slabs. Once the slabs are dry and the plants removed, remove the plastic wrap and stack the slabs on pallets *(Plate 14)*. Leave enough space between the slabs for steam to penetrate. To prevent damage to the bottom slabs, do not stack slabs more than 1 m high. Cover the stack of slabs with plastic and introduce steam *(Plate 15)*. Apply a temperature of 90°C for 30 minutes, measured in the middle of the stack, to disinfect the slabs. Alternatively, to avoid the need to check the temperature of the stack, steam the slabs overnight. Let the slabs cool, then wrap them in new plastic, seal them and place them in the greenhouse ready for the next crop.

Coir or Coco Peat

Coir is a relatively new growing substrate in Ontario that has become popular over the past few years due its competitive price and ease of disposal at the end of the cropping season. It is an organic substrate made of waste materials from the coconut fibre industry. To create it, the long fibres from the coconut husk are removed and the remaining material is screened and graded. The result is spheres of various diameters with a high water-holding capacity, high porosity and medium-to-high cation-exchange capacity. The material has a pH of 5.6–6.5 and a bulk density of 82 kg/m^2. After treatment to remove excess salts, the material is dried, compressed in cakes and packaged in polyethylene bags before shipping.

It is used in a layout similar to rockwool production, with the following differences:

- Soak the bags with a nutrient solution that has a calcium level about 10% higher and a potassium level about 10% lower than the solution used for rockwool fertigation.
- Before placing plants, fully saturate the coir to allow the fibres to regain their natural state.
- If precut bags are used, be sure to saturate them completely.

- Adjust water management based on the characteristics of the coir.

The size and uniformity of particles in the coir slab determine its water-holding capacity and the amount of water available to the plants. In some cases the mix of particles produces a slab that is very generative, requiring more frequent watering, which is better for production when light levels are low. In other cases, the particle mix creates a slab that is very vegetative, requiring adjustments to the water regime to prevent overwatering. This variability exists from brand to brand and, in some cases, from bag to bag.

Coir re-wets easily and drains quickly, allowing easier steering of the plant. At the end of the cropping cycle, coir can be composted.

Nutrient Film Technique (NFT)

Nutrient film technique (NFT) is a method of growing plants in a continuous shallow flow of nutrient solution. This technique is a true hydroponic culture, where the bare roots of the plants are bathed in a nutrient solution that is recycled in a closed system. This saves both fertilizer and water and reduces the impact on the environment.

The basic design consists of a reservoir tank and components such as pumps, a solution delivery network, growing troughs and a solution return system. The nutrient solution is pumped from the reservoir to the top end of the growing trough, flowing by gravity to the return line and back to the reservoir. The growing trough is set on a slope of 1–2% to facilitate the flow of the nutrient solution.

Reservoir Tank

The reservoir tank for an NFT system is located below grade to allow for a gravity-fed return flow of the nutrient solution (Figure 3–5, *NFT Tank Setup)*. The tank can be constructed in a variety of ways:

- concrete blocks assembled to form a tank
- concrete poured to form a tank
- concrete crocks buried in the ground, with a cement floor
- rigid plastic tanks buried in the ground or placed as inserts in concrete casings
- a pit with wooden walls lined with a swimming pool liner

If concrete is used, it must be painted with a rubber-based, non-phytotoxic paint to protect the concrete from the nutrient solution.

Reservoir tanks are usually designed to have a 5,500 L/0.5 ha capacity with 4,000–4,500 L of water in the tank. Meanwhile traditional NFT systems are designed to have approximately 13,500–13,750 L/0.5 ha of nutrient solution circulating in the greenhouse. Provisions should be made to store this water in case of electrical power failure. The tank is equipped with an automatic freshwater intake used to top it up with fresh water whenever the level in the tank drops below a set point.

Pump System

The pumping system must be able to deliver a high volume of water (at least 2 L/min/emitter) at a low pressure, be reliable, and be equipped with stainless steel or plastic impellers and components. Normally, systems are designed with one 5-HP pumping station per acre (0.4 ha). In this case, a standby 5-HP pump should also be installed and equipped with a sensor to automatically switch it on when required.

A more economical technique is to install three pumps of 2 HP each in parallel, all running at once. If one of the pumps fails, the two remaining pumps are capable of supplying enough solution to the crop to minimize crop injury while repairs are conducted.

As a safety feature, keep a spare motor. Since electrical disruption can cause crop devastation, all facilities must have a standby electrical generator that can provide enough electricity to power the pumps and other essential greenhouse equipment (e.g., heat, vents, computers, etc.).

An added benefit of using three 2-HP pumps in parallel is that the extra pumping capacity allow growers to increase the solution flow rate of 2 L/min/trough if required. The extra capacity can also be used to aerate the tanks or send the nutrient solution to the in-line monitoring system and to the heating and pasteurization systems. This removes the need for an extra pump to supply nutrient solution for these purposes.

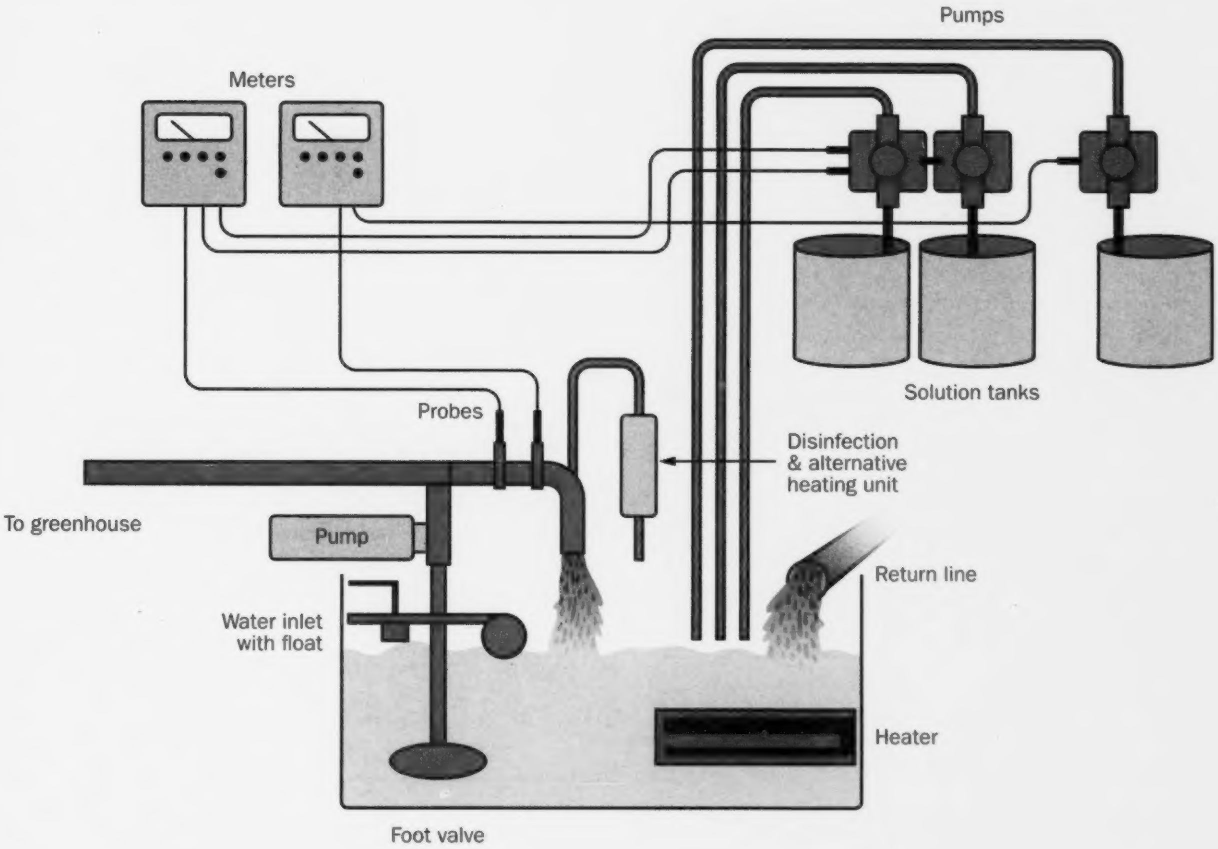
pH and EC Controllers

The pH and EC of the nutrient solution is continuously monitored by in-line probes. If the reading varies from the set point established by the grower, the pH and EC controllers automatically trigger the attached nutrient solution dosing pumps (Figure 3–5, *NFT Tank Setup*). This system adds fertilizer and acids on a continual basis as required. A time-out switch on the controllers prevents overdosing. This is an important safety feature, since excessive fertilizer or acid can harm the crop. As a safety measure, install a second set of pH and EC monitors as a check on the primary controllers.

A computerized fertilizer injector system can also be used to monitor and adjust the nutrient solution. The advantage of such a system is that it can:

- monitor several NFT reservoir tanks from a single unit
- maintain the integrity of the nutrient solutions for each NFT system
- allow for different feed schedules (e.g., older crops vs. younger crops) to be maintained in each system.

Figure 3–5. NFT Tank Setup


Pumps
Meters
Solution tanks
Probes
Disinfection & alternative heating unit
To greenhouse
Pump
Return line
Water inlet with float
Heater
Foot valve

Temperature Control

The optimum solution temperature is 18–21°C. Usually the solution temperature reflects air temperature: as the air temperature increases during the day, so does the temperature of the nutrient solution. Similarly, when the air temperature decreases at night, the nutrient solution temperature will also drop. An additional heating source is therefore necessary to maintain a constant solution temperature, especially when adding fresh water. Stainless steel heating coils are placed in the reservoir tank or, more commonly, in a small auxiliary tank. The main pump delivers the nutrient solution to the auxiliary tank via a side loop. Once the solution is heated, it is allowed to return to the reservoir tank.

As the temperature of the nutrient solution increases, the dissolved oxygen in the nutrient solution decreases. This may become a problem in the summer, especially when planting a fall crop. Because the young plants initially do not provide adequate shade, the radiant energy from the sun heats up the nutrient solution. Temperatures as high as 30°C are not uncommon. Well water is used to cool the nutrient solution.

Disinfection

A disinfection loop in the NFT system that siphons off 25% of the nutrient solution is used to partially disinfect the nutrient solution. Completely disinfecting the nutrient solution is not recommended because a sterile solution allows rapid proliferation of microbial populations. In contrast, a partial disinfection reduces the microbial population in the solution but doesn't eliminate it, creating a balance between beneficial and non-beneficial microbial populations.

Most growers install a ultraviolet (UV) disinfection system that allows 25% of the nutrient solution to pass through UV lamps and back into the reservoir tank. Ozonation is another method of disinfecting the nutrient solution. However, it requires special customized systems to avoid plant injury and ensure efficiency. While slow sand filtration is an effective technique, it is not commonly used for NFT systems, since very large systems would be required to handle the volume of water and the flow rate necessary to effectively treat the nutrient solution.

Aeration

The nutrient solution must be aerated to ensure that the plants get enough oxygen for their root systems. Creating a large drop between the return line and the level of solution in the tank provides good agitation and helps replenish the oxygen. An aeration loop, using a venturi system, also improves oxygenation by forcing air into the nutrient solution. Injecting oxygen into the nutrient solution is another way to maintain adequate oxygen levels.

Plumbing for Nutrient Solution Distribution and Collection

The nutrient solution delivery system must be designed to ensure that all troughs receive the same flow rate (2 L/min/trough) (Figure 3-6, *Layout for NFT Emitters and Return Line*). A 75-mm main header from the pump set delivers the nutrient solution to a 37.5–50-mm subheader. The subheader then delivers the solution to a 19–25-mm sub-subheader at each zone, from which a 4-mm flexible tube delivers at least 2 L of nutrient solution per minute per trough. A well-designed system will require little or no balancing between zones to ensure even water distribution. PVC is used for all plumbing components since the nutrient solution can corrode galvanized pipes, releasing zinc ions that may damage the crop.

The intakes for the pumps are usually located near the bottom of the reservoir tank and require a basket filter with a one-way check valve at the bottom. This is crucial in case of a power failure, since these pumps do not need to be primed once the generator restores electricity.

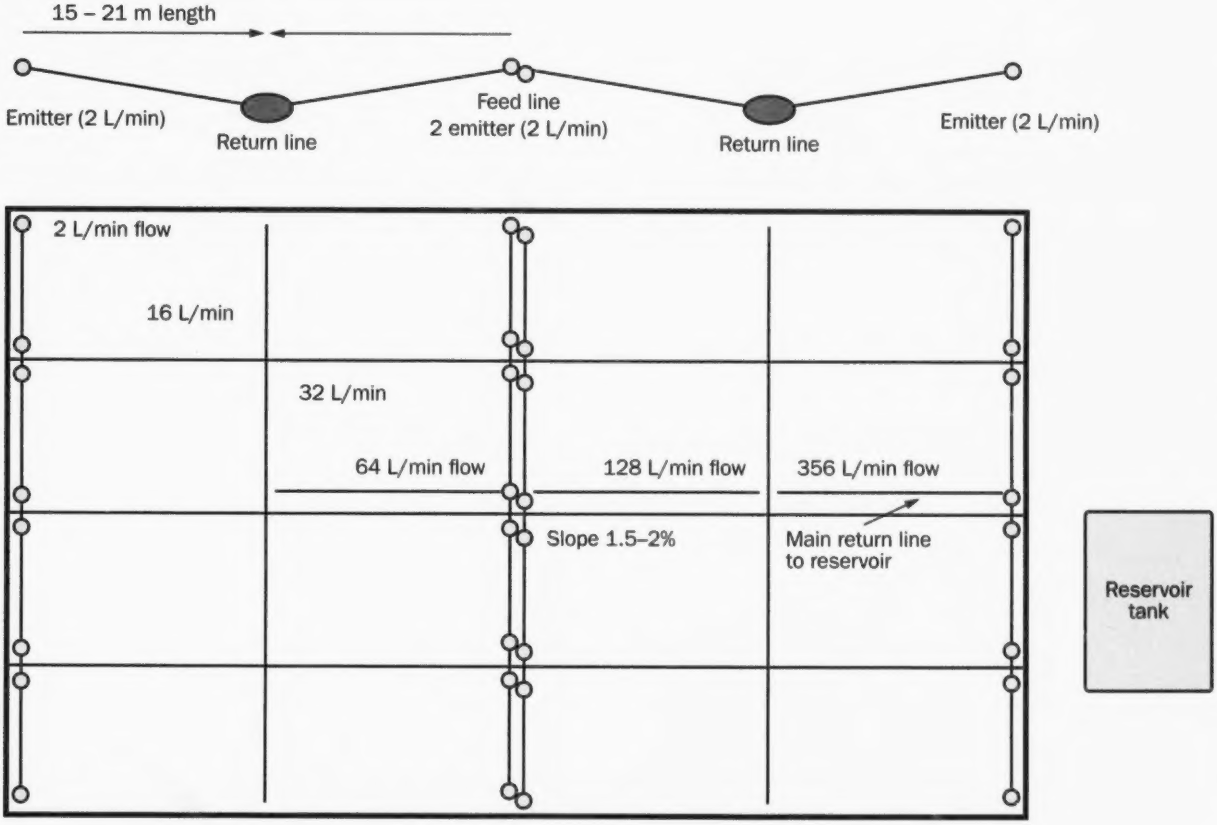
The return line is buried in the ground and consists of 10-cm sewer pipe, which is durable, inexpensive and easy to install. Holes cut into the pipe or "T" junctions located at every trough return location allow the solution to flow from the growing trough into the return line. The solution flows by gravity to the reservoir tank. A 0.5% slope is usually adequate. A large drop between the return line and the top of the nutrient solution is necessary to ensure maximum mixing of the return solution with the solution in the reservoir. The increased agitation enhances solution aeration, while baffles placed at the end of the return line may also increase agitation, improving aeration. A coarse filter (e.g., a nylon stocking placed over the opening) will trap any root pieces or other material that may clog the pump impellers.

Growing Trough

Numerous types of troughs are available. These vary from aluminum troughs with plastic covers to preformed rigid plastic troughs with flaps to 6-mil white-on-black polytubes. In all cases, the purpose of the trough is to provide a channel for the nutrient solution to flow through and for the roots to grow in. The least expensive system is the 6-mil polytube laid on styrofoam that is 4 cm thick and 20 cm wide. A wide shallow groove, running along the length of the styrofoam, channels the nutrient solution towards the middle of the trough. This is especially important in the early stages of the cropping cycle to ensure that all plants receive nutrient solution. However, too deep a channel results in poor aeration, decreasing the amount of oxygen available to the roots, which in turn decreases performance and encourages root die-back and diseases.

Ideally the trough should have a slope of 1.5%–2%, be 15 m long and be 30 cm wide at the base. If the trough is longer than 21 m, modifications to the slope and flow rate must be made.

Figure 3–6. Layout for NFT Emitters and Return Line


15 – 21 m length
Emitter (2 L/min)
Return line
Feed line
2 emitter (2 L/min)
Return line
Emitter (2 L/min)
2 L/min flow
16 L/min
32 L/min
64 L/min flow
128 L/min flow
356 L/min flow
Slope 1.5–2%
Main return line
to reservoir
Reservoir
tank

Indicates estimated flow rate of water at location

Phytotoxicity

It is important to ensure that all components of the NFT system are non-phytotoxic. Do not use metal components (galvanized pipes or copper pipes) because they corrode and release micronutrients, such as zinc or copper, that will accumulate to toxic levels. Plastic components in the irrigation lines, as well as the growing trough, must be non-phytotoxic. Components in some flexible plastics are extremely toxic to plants.

Soil Culture

The number of growers using this medium has declined. However, some smaller greenhouse operations in isolated areas continue to produce good greenhouse vegetable crops using soil. Drip irrigation or tape irrigation is commonly used to grow soil crops in the greenhouse.

Type of Soil

To achieve maximum production, growers should have a well-aerated soil that is rich in nutrients, high in organic matter content and free of pathogens and that also has good drainage. The most suitable soils are loam, sandy loam and some silty loam types. Other soil types may be used but require proper management and higher input costs to achieve maximum productivity. For example, early winter production in a heavy clay soil requires the installation of tile drains, the addition of organic matter content before the cropping season to aggregate soil particles, and careful water and nutrient management to achieve success. Sandy soils with poor water-holding capacity require frequent watering (with nutrients), which leads to increased potential for groundwater contamination. This problem can be overcome with a collection system designed to catch and recycle the excess water.

Drainage

A well-draining soil is best for greenhouse vegetable production. A tile drainage system installed in ground beds ensures all excess water is carried away. Contact a local agricultural drainage company to help design the system. Generally, 10-cm-diameter tile set 35 cm deep and 45–60 cm apart with a slope of 10 cm in 150 m is adequate.

Flooding and Leaching

Prior to planting, the soil should be irrigated to bring it to field capacity. The amount of water required to do this varies depending upon the soil type and the soil moisture content at the time. In general, use 20–50 L/m^2. Water leaching (100 L/m^2) may be necessary in some soils to lower high levels of ammonium and manganese, especially in soils that were steam pasteurized.

Soil Pasteurization

Harmful pathogens (bacteria and fungi) are present in most soils, along with weed seeds and insects. Soil pasteurization will eliminate them. Soils should be in fine tilth to allow rapid, uniform penetration of the steam or fumigant. Large clods or lumps of dirt and undecomposed crop remains (stems and roots) may hinder full penetration.

Under ideal conditions, heating the soil to 60°C for 30 minutes will eliminate most organisms of concern except viruses (Table 3–1, *Time–Temperature Requirements to Destroy Undesirable Organisms*). Heating the soil above 82°C eliminates beneficial organisms as well and sterilizes the soil, making it vulnerable to a greater degree of infection than before.

Other undesirable side effects of over-heating are:

- excessive ammonia release
- manganese toxicity
- destruction of organic matter
- higher total salt level

Table 3–1. Time–Temperature Requirements to Destroy Undesirable Organisms

	Time (min.)	Temperature (°C)
Weeds (most)	15	70–80
Insects + mites	20	60–71
Bacteria (most)	10	60
Fusarium	30	57
Botrytis	15	55
Nematodes	15	55
Rhizoctonia	30	50
Sclerotina	5	50
Pythium	40	46

Source: W.R. Jarvis. Managing Diseases in Greenhouse Crops *(APS Press, 1992).*

Greenhouse soils can be steam pasteurized by injecting steam through agricultural tile drain. Covering the soil surface with a plastic sheet to trap the steam in the soil greatly enhances its effectiveness. Alternatively, if the drain tile is in disrepair, steam can be injected directly under a specially formulated plastic steam tarp. Bury the edges of the tarp in the soil, covering a 10–12 cm margin on each edge, so that when the steam is injected at a pressure of 41–48 kPa (6–7 psi), it does not escape. The temperature of the soil must be monitored to ensure that an adequate temperature has been achieved to pasteurize the soil without over-heating it. (Always leach the soil after steam pasteurization.)

Chemical fumigants may also be used, although the choice is limited. Follow the manufacturer's label direction for rate, duration and venting periods to safely and effectively use these products.

Organic Matter

A high level of organic matter helps maintain a stable soil structure and improves the water-holding capacity and aeration of the soil. Coarse peat at rates as high as 500 m^3/ha may be incorporated into new soils to improve their condition. Peat is acidic (pH 4.0) and therefore lowers the pH of the soil. This is a benefit for alkaline soils but must be corrected in acidic soils by adding lime (5 kg of limestone/m^3 of peat).

The organic matter in greenhouse soils decomposes quite quickly, so apply 100 m^3 of peat/ha each year. Incorporate both peat and lime in the soil prior to the main cultivation. Composted manure may be incorporated to increase organic matter content, but weed and herbicide contamination may cause severe crop losses.

pH Control

Greenhouse vegetables grow reasonably well within a wide range of soil pH levels (5.5–7.5), but a pH of 6.0–6.5 for mineral soils and 5.0–5.5 for organic soils is generally accepted as optimal. To raise the pH of the soil to the desired level, use either ground calcitic limestone (3 tonnes/ha for each 0.5 pH unit increase for most light soils) or dolomitic limestone (if the soil magnesium level is low).

Adding peat to the soil for organic matter amendment lowers the pH of high-pH soils. Alternatively, soil pH can be reduced by adding elemental sulphur (flowers of sulphur) at 50–100 kg/ha for each 0.5–1.0 unit of pH decrease or apply ordinary sulphur to the soil and incorporate it into the top 15–30 cm of the soil. Do this several weeks before planting, keeping in mind that the reaction will be slow in cold soils. The amount of sulphur required varies between soils, depending on the buffering capacity (exchange capacity) and the original pH of the soil.

The pH of the soil around the plant roots is more critical than in the walkway. Adjusting the pH at the plant site can easily be accomplished through drip irrigation by adding phosphoric or nitric acid to a complete nutrient solution to achieve a pH of 5.5. This will maintain clean irrigation lines and drippers, as well as lower the pH around the root zone, enhancing plant growth.

Drip Irrigation

A drip irrigation system:

- allows growers to regulate the amount of water and fertilizer reaching the crop
- reduces humidity of the greenhouse
- allows the use of white polyethylene film as a light-reflecting mulch
- keeps the produce clean

The irrigation system is designed to deliver nutrient solution to each plant through a series of pipes with in-line emitters or hose-end drippers at 2 L/hr/plant. A nutrient solution containing all required fertilizers is applied 3–4 times/day to meet the water and nutrient needs of the plant. The type and quantity of fertilizer and the volume of water applied will depend on the type of crop grown, stage of crop, time of the season, light level, temperature of the greenhouse and water-holding capacity of the soil.

Each day, evaluate the condition of the soil approximately 10 cm away from the plant and 10–15 cm below the surface to determine the beginning and length of the irrigation cycle. The pH and EC measurements of this sample also help to indicate the nutrient status of the soil. To measure pH and EC, first mix the soil sample with tap water (1 part soil to 2 parts water). A pH reading of 5.5–6.5 and an electrical conductivity reading of 0.9–1.2 mS/cm is considered ideal. Information from these quick tests will assist in determining how much fertilizer and water the crop requires.

To set the required fertilizer schedule, it helps to have a laboratory soil analysis of a composite soil sample taken from several locations in the greenhouse. In the early stages of the cropping cycle, conduct this analysis weekly. Later, every 2–3 weeks is sufficient. More frequent testing may be necessary if crop production problems occur.

4. Plant Raising

A proper start is essential to obtain a uniform, high-yielding crop that produces a good-quality product. A poor start invariably results in a less-than-satisfying finish, requiring extra work to obtain a good crop, and lower economic returns. There are three critical phases involved in raising plants (which may include grafting):

1. seed
2. sowing and germination
3. raising transplants to a finished product

Seed

Use seed of the highest quality to ensure a good start. Most seed supplied to the greenhouse vegetable sector has been cleaned, treated and tested for germination/ viability. This information is usually printed on the package or is available from the seed supplier. The germination test is conducted by a certified seed laboratory and performed according to strict, standardized guidelines. Germination is defined as the emergence of the radicle from the seed coat. In most cases, the percent germination will be 75–90% for tomatoes, 95% for cucumber, 85–95% for peppers and 95% for lettuce. Thus, the number of seed ordered must be adjusted accordingly.

To the grower or plant raiser, a more critical value is the percent emergence, defined as the ratio of the number of seedlings that emerge from the growing media to the number of seeds sown. Emergence is influenced by numerous factors including:

- seed vigour
- depth of sowing
- moisture level in the media
- media aeration
- media temperature

The difference between percent germination and percent emergence may vary as much as 10%–20%.

Note that rate of seed germination varies dramatically: some seeds germinate very rapidly, while others are slower. Seeds can be grouped into three categories based on germination (see Table 4–1, *Seed Germination Categories*). The percentage in each category varies with species, cultivar and seed quality and fluctuates yearly.

Table 4–1. Seed Germination Categories

Category I	Category II	Category III
Seeds emerge 2–3 days after sowing	Seeds emerge 3–4 days after Category I Seed	Seeds emerge 3–4 days after Category II Seed and have twisted cotyledons, or blind shoots, etc.

Categories I and II are true emergence and only these should be transplanted. Sow 25% more seeds than the number of plants required. This will provide some additional high-quality plants that can be used to compensate for loss due to handling, etc. For guidelines on the amount of additional seed required, see Table 4–2, *Seed Requirements.*

Table 4–2. Seed Requirements

	# Plants Needed	# Seeds Ordered
Tomato	10,000	12,000–13,000
Cucumber	6,500	7,500*
Pepper	10,000	12,000–13,000
Lettuce	1,000	1,100–1,200

** Cucumber seed, in general, has a higher percent germination and emergence.*

Sowing and Germination

Sowing seed is a simple but critical step of plant raising. Ideally, growers should use a media with good drainage, water-holding capacity and aeration, such as rockwool or OASIS plugs. These are available in various sizes, either in styrofoam trays or plastic flats. If the trays are reused, thoroughly disinfect them before each use.

Place seeds on the dimpled surface or in the hole of the plug and cover them with medium vermiculite. An even sowing depth is essential to ensure uniform emergence and seedling development. Seed placed too deep in the growing media may take 2–3 days longer to emerge and may be weaker and slower to develop true leaves. Meanwhile, seed placed on the surface is prone to drying out. In some cases the radicle may not anchor properly, causing seedlings to fall over.

Prior to sowing, pre-soak the growing media with clear water or a dilute complete nutrient solution (electrical conductivity 1.0–1.5 mS/cm) at 20–25°C. After sowing, gently water the growing media to dampen the vermiculite. Ideally, place the flats/trays in a germination chamber or on benches with heating supplied either under the flat or under the bench. Cover the flats on the benches with a 2-mil clear polyethylene sheet to prevent them from drying out *(Plate 16)*. To ensure uniform, rapid emergence, maintain the ideal media temperature specified in Table 4–3, *Germination Temperatures.*

Table 4–3. Germination Temperatures

Crop	Growing Media Temperature (°C)
Tomato	25
Cucumber	27
Lettuce	16–18
Pepper	26

After 60–75% emergence occurs, remove the flats/trays from the germination chamber or take off the poly cover. This is usually done 60–96 hours after seeding, depending on the type of crop and cultivar grown (See Table 4–4, *Approximate Hours for Germination*). If this change is carried out too early, the emergence of Categories II and III seeds will be delayed. If it is carried out too late, it will result in the stretching of the Category I seedlings that have already emerged. Once maximum emergence — more than 80% — occurs, gradually lower the air temperature to 19–20°C for tomatoes, 21°C for cucumbers and 20°C for peppers. In most cases, a drop of 1°C per day is ideal. Adjust temperatures according to light levels (Chapter 1, page 3) to obtain the plant at the desired time. Too large a fluctuation between day and night temperatures results in elongated plants.

Table 4–4. Approximate Hours for Germination

Crop	Hours for Germination
Tomatoes	
Good germination	72
Poor germination	96
Peppers	72–96
Cucumbers	48–60
Lettuce	72

Once the true leaves emerge, water the flats with a complete nutrient solution, starting at 1.0 mS/cm EC and gradually raising the electrical conductivity (EC) to about 3.0 mS/cm prior to transplanting. Overwatering results in poor aeration of the media, limiting root development. As well, excess moisture (especially applied as a mist) causes the root zone temperature to drop, delaying growth and increasing variability between the plants. If the media is too dry, plant growth slows, leaf size is smaller and the EC of the media increases. The weaker plants may not survive or, if they do, will be more prone to disease.

Transplant seedlings into rockwool blocks once they reach the desired size. Too long a period in the flats (more than 21 days for tomatoes and peppers, 10 days for cucumbers) results in overcrowding, stretching and weakening of the seedlings.

Supplementing with carbon dioxide (CO_2) and high-pressure sodium light improves growth and helps establish good roots. Keep the following guidelines in mind:

- Under good light conditions, supplement CO_2 to 1,000 ppm. Because seedlings are extremely sensitive, it is essential to use a clean CO_2 source, such as liquid CO_2.

- Using supplementary high-pressure sodium light (40 watts/m^2) enhances seedling development. Use an 18-hour photoperiod for tomatoes, peppers and lettuce and a 24-hour photoperiod for cucumbers.

Transplant Raising

Seedlings are ready to transplant when the first true leaves have fully emerged and/or when the seedlings touch one another.

On average, tomatoes are ready to transplant 14–21 days after sowing; cucumbers, 7–10 days after sowing; and peppers, 14–21 days after sowing.

However, this varies depending on:

- the cultivar
- seedling vigour
- light
- temperature
- nutrition
- moisture

A short sturdy seedling is desirable. Ideally, seedlings should have a thick stem, dark-green leaves and a well-developed root system filling the plug. Before removing the plugs, soak the trays with nutrient solution to allow the plugs to easily slide out of the tray. Handle the seedlings carefully. The stem may be very brittle and may snap when handled, or it may be soft and easily damaged. Pop the seedlings out of the tray using a plug popper. Handle seedlings by the cotyledons.

To prepare the rockwool blocks for the transplants, soak them with a complete nutrient solution (EC 2.0 mS/cm, pH 5.8) by immersing the blocks in a tub filled with a complete nutrient solution or by overhead watering. It is important to soak the blocks thoroughly and uniformly to ensure proper seedling establishment. Dry blocks restrict root development and growth, increasing plant-to-plant variability.

Place seedling plugs in holes in the blocks. A common practice used for tomatoes, and increasingly for peppers as well, is to fold the lower part of the stem into the hole and push the root plug down to fill the hole. Roots will develop along the stem within the hole, anchoring the seedling and keeping the cotyledonary leaves closer to the surface of the rockwool block. This technique results in a sturdier transplant but requires seedlings that are soft and easily manipulated.

Place the transplants in trays (4–8 blocks/standard flat) that are then placed on heated benches or on a heated concrete floor. Alternatively, place the transplants directly on the floor (ebb and flood system) at 24–36 plants/m^2 *(Plate 17)*. Transplants are ready for planting directly onto the rockwool slab, growing media bag or Nutrient Film Technique (NFT) troughs in the main production area when:

- tomatoes — the first flowers are showing
- cucumbers — 4–5 true leaves are visible
- peppers — the flower at the first branching level is opening

NOTE: Roots must be well developed in the block and not overcrowded to allow for rapid penetration into the growing media once plants are placed in the production facility.

If needed, support the plants using a thin bamboo stake 20–30 cm long. This encourages development of larger transplants that are more easily handled and allows more time before plants need to be tied after transplanting.

Alternatively, new transplants can be moved directly into the production houses. Place the blocks on the rockwool slab beside the hole, and place the drippers in the block. Use the irrigation system to water the blocks. This method saves on labour but increases heating costs, since the whole greenhouse operation must be heated.

After transplanting, maintain the greenhouse temperature at 23–25°C, 24 hours/day for 3–4 days and then gradually lower the temperature. (See Chapters 5–9 for temperature regimes for specific crops.) In a starter house, using supplementary lighting (40 watts/m^2) and CO_2 (1,000 ppm) increases the rate of root and shoot growth, resulting in earlier flower bud development. Keep a photoperiod of 18 hours for peppers and tomatoes and 24 hours for cucumbers.

If plants are placed directly into the main production greenhouse, supplementary light is not effective but additional CO_2 is beneficial. Use 1,000 ppm on sunny days and 400–500 ppm on cloudy days.

Water transplants with a complete nutrient solution. Start at a low EC (2 mS/cm) and gradually increase it by 0.25 mS/cm/day up to 3 mS/cm, similar to the regime for emerged seedlings. In order to maintain a controlled growth, increase the EC further if:

- the rate of plant growth is too fast
- the available light is low
- the temperature in the greenhouse is low
- the relative humidity (RH) is high
- the moisture in the block is high

When to Water

Water in a timely manner and ensure that leaves are not wet for extended periods of time, especially later in the day. Use either overhead watering or sub-irrigation. To determine when to water, use the weight method:

1. Weigh several blocks with transplants when saturated to establish a baseline.
2. Monitor the weight of several blocks daily.
3. When the average block weighs 50% less than the saturated weight, begin watering. For a 10 × 10 × 7.5 cm block, this means watering when it weighs approximately 300–350 g.
4. When watering, ensure the blocks are re-saturated.

Transplants placed directly in the production greenhouse require more frequent watering because the lower relative humidity in the greenhouse means that they lose water from the surface of the block as well as through transpiration. Night watering may be necessary on cold nights when the humidity in the greenhouse is low.

Grafting

Today, more greenhouse operations are grafting desired cultivars onto rootstocks with stronger root systems. Tomatoes and eggplants are grafted more frequently than cucumbers and peppers.

Grafting is used to:

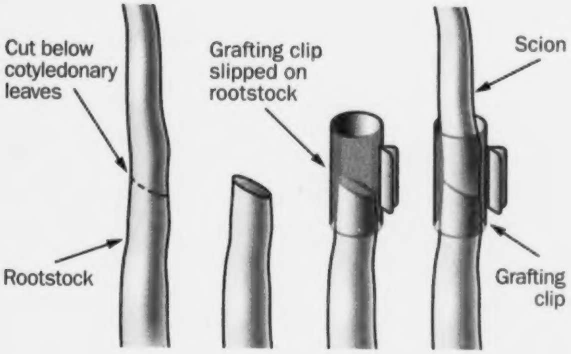
- overcome shortcomings in the disease tolerance/resistance of the desired cultivar
- improve plant vigour and performance over a wider range of greenhouse climates and root zone conditions

A desirable cultivar (scion) is attached to a rootstock selected for its strong root system with higher disease resistance. The most commonly used rootstocks for tomato production in Ontario are Beaufort, Maxifort and Emperador. Several new rootstock lines are under evaluation by the seed companies.

The following procedures will increase the likelihood of successful grafts:

- Sow rootstock seed 4–10 days before sowing the desired cultivar. This difference will depend on the rootstock used. (Check with the OMAFRA greenhouse specialist or seed supplier for more details.)
- After true leaves begin to emerge (about 14–15 days after sowing), lower the temperature for 2–3 days to strengthen the stems *(Plate 18).*
- Designate an area specifically for grafting that can be isolated. All surfaces should be sterilized. Minimize cross-traffic of workers to reduce the risk of contamination.
- Cut the rootstock at a 45-degree angle below the cotyledon leaves using a sharp razor blade *(Plate 19).*
- Place the clip at the cut surface of the rootstock *(Plate 20).*
- Similarly, cut the desired cultivar above the cotyledon leaves at a 45-degree angle. Make sure the scion is approximately same diameter as the rootstock. Next, slip the scion into the clip attached to the rootstock *(Plate 21).* Align the cuts to match so that the cut surfaces are touching. Cuts must match to ensure success *(Plates 22, 23)* (Figure 4–1, *Schematic of Japanese Top Grafting*).

Figure 4–1. Schematic of Japanese Top Grafting


Cut below cotyledonary leaves
Grafting clip slipped on rootstock
Scion
Rootstock
Grafting clip

NOTE: Conduct this process in an aseptic environment and maintain a sterile work area and sterile equipment at all times. Do not delay the grafting process once started, because the loss of moisture from the cut surfaces will delay the knitting of the two stems.

- Place grafted seedlings in a chamber or a tent-like structure in the greenhouse where light, temperature and humidity are controlled to minimize water loss from the grafted seedlings and to promote rapid knitting of the rootstock to the top.
- After 3–4 days, gradually acclimatize the grafted seedlings to ambient conditions over a period of 3–4 days.
- Transplant the seedlings into blocks 10–12 days after grafting.
- Use normal transplant-raising techniques to grow the plants. Once the plants reach the desired height and development stage, transplant them into the production area.

Grafted plants tend to be vigorous and must be grown in conditions that promote generative plants (see Chapter 1, page 1). Without generative conditions, the first set may have misshapen flowers and small or poor-quality fruit or, in a worst-case scenario, aborted flowers.

5. Tomato

Tomatoes are the most widely grown greenhouse produce in Ontario. Since the early 1990s, nearly all tomato production has focussed on the beefsteak-type tomato, which is a large-fruited, red-coloured tomato. The optimal fruit size is 200–250 g (28–34 count per 6.8 kg box). From the mid-1970s until the late 1980s, the pink-coloured tomato was widely grown. This tomato was geared for a specific market and was resistant to the Fusarium crown and root rot that afflicted the Ontario greenhouse sector in the 1970s. Consumer demand, as well as the transfer of the disease resistance to the red-coloured tomato cultivars, drove the shift to beefsteak tomatoes, resulting in little or no pink tomato production in Ontario today.

Further change in consumer preferences has resulted in an increase in the production of cluster tomato (tomatoes on the vine, or TOV). This is a slightly smaller tomato than the beefsteak-type and is harvested on the truss/cluster and marketed as a bunch. As well, specialty-type tomatoes such as Roma-type, cocktail, cherry, yellow-coloured and orange-coloured tomatoes, grown for niche markets, are increasing in popularity.

Two crops of tomatoes are traditionally grown per year. The spring crop is planted in the greenhouse in the last week of December, with harvest beginning in mid-to-late March and crop termination in July. A fall crop planted in August follows. Harvest begins in October, and the crop is terminated in November or December. To decrease downtime, intercropping is becoming more popular (see *Raised Trough System*, page 19). Alternatively, a single long-season crop can be grown, with planting in mid-December, harvest beginning in mid-to-late March and a finished crop in September/October. The single-crop system is most common in the Leamington area, while the two-crop system is more commonly used throughout the rest of the province.

Operators adjust the start and finish of the crop to suit market demand, as well as available light. The trend to earlier planting continues as the design of greenhouse structures and climate controls improves and early-season prices remain high. Producing marketable tomatoes during the winter months — November, December, January and February — can be carried out using artificial lighting. To be successful, however, it requires a large capital investment, low electrical rates and high marketplace returns.

The crop must get off to a good start to achieve successful tomato production. Healthy transplants with well-balanced growth during the winter months can result in excellent production of high-quality fruit. It is the grower's challenge to strike a balance between vegetative and generative growth. An overly vegetative crop has a large leaf area, delayed flowering, poor fruit set, smaller fruit and delayed harvest. In addition, it is more prone to diseases. In contrast, a plant that is too generative has a high fruit load, smaller leaves and a weaker growing point, resulting in poor and delayed fruit set until the fruit load is decreased, plus overall lower production.

Cultivars

There are a limited number of beefsteak tomato cultivars suitable for the Ontario greenhouse sector. The consumer demand for a high-quality, large-sized red tomato limits the choice. Some characteristics to keep in mind are:

- yield
- fruit size
- growth habit
- resistance to russetting (shrink cracking)
- calyx length
- fruit firmness
- taste
- plant habit

New cultivars released by the seed companies should be tested in Ontario greenhouses before being grown on a larger scale. Cultivars with powdery mildew tolerance are available and may become more important in the future.

Contact the OMAFRA greenhouse vegetable specialist or your seed company for more details on tomato cultivars.

Cropping Schedule

There are two common cropping practices in Ontario: a spring/fall crop or a long-season crop. Adjust sowing and planting dates based on available light and market commitments. A general cropping outline is indicated in Table 5–1, *Cropping Schedule for Tomatoes.*

Seeding

Sow tomato seed directly into rockwool plugs in styrofoam trays or plastic plug trays. Small operations sow seed by hand, while automatic seeders are used in larger operations. Soak plugs with plain water or a complete nutrient solution at electrical conductivity (EC) 1–1.5 mS/cm before sowing. Cover seed with medium-grade vermiculite. Place trays in germination chambers maintained at 24–25°C and 100% RH. Alternatively, place the trays on germination benches with under-bench heat and cover the trays with a 2-mil clear polyethylene sheet to maintain temperature and humidity.

The optimum germination temperature for tomatoes is 24–25°C. Seed emergence occurs 2½–3 days later. After 60–70% emergence, remove trays from the germination chamber or remove the plastic film from the flat on the germination bench. Maintain the temperature at 24°C for 1–2 days longer and then gradually lower it over a 2-day period to 19–20°C day and night. After the cotyledon leaves have expanded, fertilize the seedlings with a complete nutrient solution at an EC of 1.0 mS/cm, and then gradually increase the EC as the plants develop.

Seedlings benefit from supplementary lighting (18 hour photoperiod at 40 watts/m^2) and carbon dioxide (CO_2) levels of 800–1,000 ppm.

Begin transplanting 14–21 days after sowing or when the leaves touch the neighbouring plant.

Use a pure source of CO_2 because seedlings are extremely sensitive to by-products of incomplete natural gas combustion.

Table 5–1. Cropping Schedule for Tomatoes

Crop Type	Sow	Plant	Harvest	Terminate
Spring/Fall Crop				
Spring	mid-November	1st week of January	mid-March to end of March	mid-July
Fall	late June	1st week of August	September/October	end of November to mid-December
Intercropping				
First crop	end of November	1st week of January	mid-March to end of March	end of July
Second crop	late June	end of July	end of September	end of November to early December
Long-season Crop				
Long season	1st week of November	3rd–4th week of December	mid-March to end of March	end of September to early October
Overwinter crop	late June	1st–2nd week of August	September/October	1st week of June

Plant Raising

Transplant seedlings into 7.5 or 10 cm rockwool blocks with preformed holes to accommodate the rockwool plugs. Begin by soaking the blocks with a complete nutrient solution (pH 5.5, EC 1.5– 2.0 mS/cm). At each subsequent watering, gradually raise the EC to eventually reach 3.0–3.5 mS/cm at the time of transplanting. The rate of increase will be determined by the available light, rate of growth, plant vigour, available moisture and temperature regime. (See Chapter 1 for more details about the interaction of these factors on plant growth.)

Place the seedlings into the hole of the rockwool block with the stem either straight or bent at 90° or 180°. Bending the seedling places the cotyledon leaves and the growing point closer to the surface of the rockwool block. This allows for root development along the buried stem, providing greater plant stability.

If seedlings are placed straight up in the hole, they must be staked. Place a thin bamboo stick close to the seedling, and use elastic bands or metal rings to hold the plants to the stake. Cover the hole with a layer of medium-grade vermiculite for added stability.

Because the stake provides support, staked plants can be allowed to grow bigger. This delays the need to tie the plants to overhead wires once they are transplanted in the production greenhouse. There is also less damage to plants when transporting them during transplantation.

Maintain the greenhouse temperature at 23–25°C for 1–2 days after transplanting seedlings to hasten root establishment. Following this, gradually lower the temperature to 19°C (day and night) at a rate of 1°C/day. Supplementary light (18 hour photoperiod at 40 watts/m^2) and CO_2 levels of 800–1,000 ppm benefit the crop by producing compact, stronger-rooted transplants with sturdier stems and earlier flowering.

During early stages of tomato plant growth, the plant tends to be strongly vegetative. To ensure early, high-quality production, it is important to create greenhouse conditions that induce a more generative growth phase, encouraging flower production. Adjust temperature, relative humidity, water and fertility in relation to the available light to control the plant *(Plates 24, 25)*. (See Chapter 1 for more details about the interaction of these factors on plant growth.)

Wait until the first flower cluster is well established (about 6–7 weeks after sowing) and/or the first flower begins to open before transplanting seedlings to the production greenhouse. This decreases the possibility of the plant being too vegetative after transplanting in production greenhouses. If transplanting occurs too early or the plant growth is not controlled, the plant remains too vegetative. This results in delayed flowering and first harvest, a tendency for smaller, misshapen fruit and a plant more prone to disease infection. On the other hand, a plant that is too generative results in strong flower production, a weak top, slower growth and delayed harvest. The objective at this stage is to strike a balance between generative and vegetative growth.

Since 2002 there has been an increase in the number of growers using grafted tomatoes to help combat root diseases and improve plant vigour during summer and fall, especially when growing a single long-season crop (see *Grafting*, page 32). It is important to control the early growth of the grafted plant by adjusting the greenhouse environment to produce a balanced plant (see Chapter 1) and thus ensure early, high-quality tomatoes.

Plant Spacing

In general, a plant spacing of 0.37–0.41 m^2 (2.4–2.7 plants/m^2) is ideal. Arrange plants in a twin-growing row 0.6–0.8 m apart, with a 0.9–1.2 m walkway separating the pairs of growing rows. Adjust plant spacing within the row to achieve the desired plant density. In rockwool culture, use 2 plants/90 cm slab with the bags spaced evenly within the row. The majority of growers are opting for a "V" system, using a single row with double the number of plants per row to achieve the desired plant density. The advantage of this widely used system is that less growing media is used and less time is required to set up the greenhouse.

When light levels are higher later in the season, plant density may be increased to 2.9 stems/m^2 by allowing a side shoot to develop into a productive stem on every 5th plant. However, care must be taken because this tends to alter the relationship between plant, rockwool volume and water, resulting in smaller-sized fruit and increased disease incidence, especially when light levels are low. Developing and training an extra side shoot to increase stem density is normally initiated in March.

Pruning and Training

Prune greenhouse tomatoes to a single stem, removing all side shoots or suckers at least once a week. Support the plants with polypropylene twine. Tie one end of the twine loosely to the base of the plant with a small, non-slip loop and attach the other end to an overhead support. Traditionally, a wire 1.8–2.5 m above the plant row is used to provide this support. However, in newer greenhouses equipped with hot-water pipe rail systems and scissors carts, overhead wires are 3.0–3.5 m high.

Proper tying of the twine at the base of the plant is important. If the knot is too tight, the plant may be damaged. If the knot is too loose, the plant may fall or slip down and snap the stem. In some cases, the twine can be placed between the bottom of the transplant block and the top of the rockwool slab, so the weight of the plant keeps the twine in place. However, problems can develop with wicking of the nutrient solution up the twine. This damages the plant where the twine and stem are in contact, resulting in a loss of production and creating potential sites for diseases such as *Botrytis*.

As the plant grows, twist the plant around the twine in one or two easy revolutions for each fruit cluster. Once the plants are larger and heavier (usually at the 4th–5th cluster stage), use plastic snap-on clips to attach the plants to the twine.

For the spring crop, drape an additional 2.0–2.5 m of twine over the top wire. As the plant reaches the wire, untie the twine and lower the plant, allowing the lower section of the plant to lie on the ground or on the wire support. This is called layering or lowering. Overhead hooks, with a season's supply of twine stored on them, are also available and are commonly used in high-wire tomato production houses. These increase the ease of lowering of the crop when layering.

Before layering, it is important to remove the lower leaves. This is done to:

- improve bottom air circulation
- maintain an ideal environment at the base after the plant is lowered
- allow workers to find the fruit easily when harvesting

Ideally, remove only 1–2 leaves at a time, because removing too many leaves all at once alters the leaf-to-fruit ratio and reduces yield. In general, aim to have just 18–20 leaves on the plant (roughly 1.2 m of leaf-bearing stem), especially in the summer months. Early in the cropping cycle, aim for just 12–15 leaves in order to maintain fruit quality and rate of fruit development. Some cultivars may require aggressive de-leafing. In this case, remove a leaf in the middle of the plant and another near the growing point when the plant is approximately at the 3rd–4th flowering-truss stage. This may need to be repeated until plant vigour is controlled (especially a problem in fall-grown crops).

Pinch off or top the growing point of the plant about 6–8 weeks before harvest is to be discontinued (2 weeks earlier for the fall crop). This transfers the sugars and energy normally used to produce new flowers and leaves to the fruit, causing them to enlarge and ripen early.

Cluster Pruning

As most modern tomato cultivars set fruit readily, all flowers on a truss may set fruit. The time between setting of the first flower and the last may be 4–10 days, resulting in a range of fruit size at harvest time. To ensure uniform size and rapid harvest, prune each cluster to 4 fruits (beefsteak tomatoes) or 5 (cluster tomatoes). Specialty tomato clusters are pruned to balance the plant and maintain fruit size and cluster quality. Once the desired flowers are properly set, prune the plant by pinching off the remainder of the flower truss. Under good light conditions, with a strong vigorous beefsteak variety or a fall crop, it may be necessary to leave 5 fruits/cluster up to the 3rd cluster and 4 fruits/cluster for subsequent clusters. This decision must be carefully considered because too much fruit load on the lower clusters severely restricts later production. Truss supports may be necessary to prevent the fruit truss from kinking *(Plates 26, 27)*.

Pollination

Pollination is necessary for normal fruit set. Pollen from the anthers must reach the ovaries at the base of the flower for fertilization and fruit development to occur. The number of seeds that develop determines fruit size, quality and shape. Tomato flowers are self-pollinating, but to ensure high-quality, uniform tomatoes, use vibrating devices such as electric bees, electric toothbrushes or bumblebees to increase pollination *(Plate 28).*

Successful pollination involves:

- production of viable pollen
- release of the pollen from the anthers to the stigma
- germination of the pollen grains on the stigma
- growth of the pollen tubes down the inside of the stigma, resulting in fertilization and subsequent fruit set

Note: Fruit with more seed present tend to be larger and better shaped.

Adverse temperatures, light and nutritional conditions cause some or all of these processes to fail and can result in poor fruit set and poor fruit quality. The day temperature should not fall below 18°C or exceed 30°C once flowering starts.

Bumblebees

Bumblebees are commonly used to pollinate tomato crops to produce high-quality fruit. Introduce bumblebee hives (2–3 hives/ha) into a tomato greenhouse once the first flower cluster is fully opened. When bumblebee workers visit the flowers to obtain pollen, many pollen grains are disturbed from the stamens, landing on the stigma and initiating pollination. The bumblebees visit flowers when pollen is available (mid-morning to early afternoon) and visit the same flower several times over the bloom period.

As the plant grows and more flowers open, add extra hives to achieve a total of 4–5 hives/ha, as determined by the bumblebee supplier, and maintain this level for the duration of the growing season. As the hive ages, the worker bumblebee population declines and the social order of the hive changes, resulting in an inefficient hive. Hives lose their pollination efficiency after 6–8 weeks. At this time, replace the hives or bring more hives in to maintain good pollination. Repeat this throughout the growing season.

A brown discoloration or marking of the flower's cone/trumpet indicates that a bumblebee has visited the flower. Monitor these marks to determine whether the bumblebees are performing well *(Plate 29).*

Place hives in a convenient location on a sturdy stand or shelf located 1.0–1.5 m off the ground. If the area is unshaded, provide a shade cover to prevent overheating in the summer. The hives must be located away from vibration or drafts. Hives placed in a cool location are slower to develop enough adult worker bumblebees to efficiently pollinate the crop.

Modern hives are designed to provide a carbohydrate source for the bumblebees, requiring little or no maintenance by the operator. Hives are also equipped with a one-way opening that, when in operation, allows the bumblebees to enter the hive but not exit it. This is necessary to capture all the bumblebees when the hives are being removed if chemical sprays are applied to the tomato crop.

Bumblebees are sensitive to various chemicals. Once chemicals are introduced into the hives or brood, they cause the hive to deteriorate, resulting in poor pollination. Thus, a good biological control program against pests is necessary to obtain the full benefit of bumblebee pollination.

While bumblebees will exit greenhouses through vents, they usually return. However, if the outside temperature is low or the vents close before the bumblebees return, these bumblebees will die, especially in February and March. This can be a problem in gutter-vented double poly greenhouses, where the wavelength of the light that comes through the vent opening is different from that of the light that penetrates the double poly, luring the bees outside.

To prevent this:

- change the poly covering to one that has less difference in light transmission
- decrease the size of the vent opening and compensate by installing end-wall fans to assist in early venting
- install bee screens at the gutter vent to prevent escapes

In small tomato greenhouses, bumblebee pollination may not be effective. The number of bumblebees in an average mature hive can be as high as 300 adult bees. When the demand for pollen is very high, excessive visits to each flower *(Plate 30)* can cause damage to the flower and in extreme cases, flower abortion. Thus, flowers should be hand-pollinated using electric bees. Backpack air blowers similar to leaf blowers can also be used to pollinate the flowers. Other methods, such as tapping the overhead wires or the string supporting the plants or using coarse water sprays, have not generally been satisfactory.

During late fall, winter and early spring, most cultivars produce flowers with a slightly different shape, making natural pollination more difficult. This is a result of low light and temperature and is occasionally aggravated by high nitrogen levels. The optimum time for pollination is between 11 a.m. and 3 p.m., when flowers are dry and pollen is shedding. Inadequate pollination results in poor and uneven seed set, which in turn causes hollow, misshapen, poor-quality fruit.

Climate

Air temperature has a profound effect on plant growth, flower development and the setting, development, ripening and quality of fruit. The 24-hour temperature affects the rate of growth: the higher the 24-hour average temperature, the faster the growth. A tomato crop achieves its maximum growth when both day and night temperatures are 25°C, but maximum fruit production is achieved when temperatures are 18°C during the night and 20°C during day or when the 24-hour average is 19°C. The temperature difference between day and night determines the shape of the plant and the degree of vegetativeness or fruitfulness.

Adjust temperatures based on available light to maintain a high rate of growth and produce large fruit of high quality. (See Table 5–2, *Recommended Air Temperatures for Tomatoes* and *Table 5–3, TOMATOES: Summary of Growing Recommendations.*) Under lower light conditions (early winter or cloudy days), maintain a lower 24-hour average temperature and then increase it when the light level increases. Adjust the day/night temperature difference to maintain plant vigour and fruit size. A large day/night temperature differential shifts the plant to a more generative phase (more flowers, thinner head, larger fruit size) while little or no temperature difference results in a more vegetative plant (fewer flowers, thicker heads).

Table 5–2. Recommended Air Temperatures (°C) for Tomatoes

	Low Light (cloudy days)	**High Light (sunny days)**	**With CO_2 (See Chapter 1, page 9)**
Night minimum (°C)	17	18	18
Day minimum (°C)	19	21	21
Ventilation temperature (°C)	21	24	26

Note: During very bright weather, temperatures higher than 26°C will not harm the plants, but above 29°C the blossoms will be injured on most cultivars.
Note: A minimum media temperature of 16°C is recommended (the optimum is 18–21°C).

Light is also a critical component of tomato production during the winter. Under winter low-light conditions, the plant tends to have long internodes, reduced flower bud development and clusters that fail to set fruit. These problems are minimized by decreasing the rate of growth through one or more of the following production practices:

- lowering the 24-hour average temperature
- lowering the volume of water applied
- raising the EC of the nutrient solution and the root zone media
- lowering the RH (raising the vapour pressure deficit)

Applying whitewash to the exterior greenhouse covering during the summer reduces both the light intensity and temperature inside the greenhouse. This results in a stronger head, improves flower quality and fruit set and decreases fruit quality problems associated with a high fruit temperature.

The tomato crop can withstand a wide range of relative humidity as long as the RH does not fluctuate drastically over a short period. Ideally, keep relative humidity at 75–85% or vapour pressure deficit (VPD) at 0.4–0.8 kPa. At high VPD, water supply to the

Table 5–3. TOMATOES: Summary of Growing Recommendations

	Germination	Plant Raising	Transplanting	Harvesting Stage	Full Harvest
Temperature*					
day (°C)	25	19–21	24	19	20–22
night (°C)	25	19–21	24	19	17–19
Solution EC (mS/cm)	0.0–1.0	2.5–3.0	2.5–3.0	2.7–3.5	2.7–4.0
Solution pH	5.8	5.8	5.8	5.8	5.8
Vol. of nutrient solution (L/day)**	—	0.2–0.3	0.2–0.3	0.5–1.5	1.5–2.5
Fertilizer schedule***	—	A	B	C	D

* *Use lower settings when light level is low.*
** *As required based on watering strategy.*
*** *See Table 5–4,* Fertigation Schedule for Tomato *for an explanation of these codes.*

Based on research conducted at the Greenhouse and Processing Crops Research Centre, Harrow, by AAFC and OMAFRA staff and at Vineland Research Station, Vineland Station, by OMAFRA staff.

crop is critical; at low VPD, incidence of diseases can increase. Low VPD during the day can improve fruit setting, while a high VPD results in poor pollination and fruit set.

Adjusting the VPD will also alter plant vigour and appearance. For example, under high VPD, the plant tends to have a thinner head and leaves. At lower VPD, the plant tends to have thicker leaves and heads, as well as flowers with extended fruit trusses that are more prone to kinking or bending, resulting in poor fruit size and shape.

Carbon dioxide supplementation benefits the tomato crop at all stages. During sunny days, use a minimum CO_2 concentration of 1,000 ppm (reduce this to 400 ppm CO_2 if the vents are opened more than 10%). Under low light conditions (40 watts/m^2), 400 ppm is ideal. In summer, when ventilation is used, it is economical and increasingly popular to apply supplemental CO_2 at concentrations up to 400 ppm, especially early in the day and in late evening, before sunset.

Horizontal airflow (HAF) fans help minimize temperature gradients in the greenhouse and uniformly distribute CO_2 throughout the canopy. An air speed of 1 m/sec is recommended. Keep in mind that HAF fans must be turned off during the dehumidification cycle for the greenhouse to be efficiently dehumidified. The convection currents created by the heating system are disrupted by the horizontal airflow, preventing the warm, moist air from easily escaping through the vents.

Nutritional Requirements

Sustained fruit production is accomplished only under optimum environmental conditions and by timely applications of water and nutrients. Regulating the supply of water and nitrogen is the most common and effective technique used to control crop growth.

A well-balanced plant is characterized by its thick stem, dark-green leaves and large, closely spaced, easy-setting flowers. A properly nourished plant should have stem that is a 1 cm thick at a point 15 cm below the growing tip. Thicker stems indicate excessive vegetative growth and are usually associated with poor fruit set and low productivity. Thinner stems usually indicate carbohydrate starvation, slow growth and, ultimately, low overall productivity.

A mature tomato crop uses 2–3 L of water per plant per day when light levels are high (on an average summer day, for example). Infrequent and low volumes of irrigation, low relative humidity and high EC in the irrigation water can all result in plants that are too generative and slow growing. However, too much growth is also undesirable. The preferred method to slow growth is by regulating EC because it is simple, effective and dependable.

A complete nutrient solution must be applied at all times to sustain the growth and fruit development necessary to obtain high production of good-quality tomatoes. The fertilizer schedule should be adjusted based on the stage of the crop. See Table 5–4, *Fertigation Schedule for Tomato* and Table 5–5, *Weights of Fertilizer Required to Make Stock Nutrient Solutions.*

Tomato plants absorb nutrients at different rates at different stages of growth. This is especially true for nitrogen and potassium. When tomato plants have 2–3 flower trusses, they absorb nitrogen at about the same rate as potassium. But as the fruit load increases, so does the potassium uptake, resulting in a 2:1 ratio of potassium to nitrogen uptake. Too much nitrogen under low light conditions early in the production cycle results in an overly vegetative plant prone to disease, poor flower development, poor fruit set and small fruit size. Lower nitrogen feed levels during this phase help control plant growth. (Note: Other factors can also strongly influence plant growth and must be considered at the same time. For details, see Chapter 1.)

Nitrogen supply can be regulated directly by adjusting the nitrogen fertilization or indirectly by varying the supply of other nutrients, such as potassium. Increasing the potassium-to-nitrogen ratio in the fertilizer solution is a frequently used technique to slow growth.

The volume and timing of the nutrient solution applied through fertigation is critical in bag culture (rockwool and coir) and greatly affects fruit quality. Begin fertigation 1–2 hours after sunrise and end it 1–2 hours before sunset. This helps decrease incidence of russetting and fruit cracking in the summer, as well as diseases. Night watering may be needed during the winter months when heating systems are fully operational and the RH in the greenhouse is low, or during the summer when light intensity and day temperatures in the greenhouse are high.

Table 5–4. Fertigation Schedule for Tomato (ppm nutrient)

	N	**NH_4**	**P**	**K**	**Ca**	**Mg**	**Fe**	**Mn**	**Zn**	**B**	**Cu**	**Mo**	**S***	**Cl***	**HCO_3**
A. Slab saturation	200	10	50	353	247	75	0.8	0.55	0.33	0.5	0.05	0.05	120–200	100–125	25
B. For 4–6 wks after planting	180	10	50	400	190	75	0.8	0.55	0.33	0.5	0.05	0.05	120–200	100–125	25
C. Normal feed	190	22	50	400	190	65	0.8	0.55	0.33	0.5	0.05	0.05	120–200	100–125	25
D. Heavy fruit load	210	22	50	420	190	75	0.8	0.55	0.33	0.5	0.05	0.05	120–200	100–125	25

* *The fertilizers selected to create the nutrient solution will determine the final level of these anions.*

Based on research conducted at the Greenhouse and Processing Crops Research Centre, Harrow, by AAFC and OMAFRA staff and at Vineland Research Station, Vineland Station, by OMAFRA staff.

Table 5–5. Weights of Fertilizer Required to Make Stock Nutrient Solutions (requires 1:100 dilution to make the final solution)

Fertilizer	A*	B*	C*	D*
	kg/1,000 L (Dilution ratio 1:100)			
Calcium nitrate	112	82.1	82.1	82.1
Potassium nitrate	25.72	42.4	40.89	56.27
Monopotassium phosphate	6.75	6.75	6.75	6.75
Potassium sulphate	45.11	38.08	39.21	31.81
Potassium chloride	3.75	3.75	3.75	3.75
Magnesium sulphate	66.0	66.0	56.0	66.0
Ammonium nitrate	0.0	4.0	8.0	8.0
	g/1,000 L (Dilution 1:100)			
Iron chelate, 13%	615.38	615.38	615.38	615.38
Manganese sulphate	207.69	207.69	207.69	207.69
Zinc sulphate	94.29	94.29	94.29	94.29
Borax	326.67	326.67	326.67	326.67
Copper sulphate	16.0	16.0	16.0	16.0
Sodium molybdate	10.87	10.87	10.87	10.87
Desired EC (mS/cm)	2.5–3.0	3.5	3.0–4.0	2.5–3.5
Desired pH	5.8	5.8	5.8	5.8
Vol. of water (L)**	0.25–0.5	0.5–1.0	1.0–2.0	1.5–2.5

* *See Table 5–4,* Fertigation Schedule for Tomato *for an explanation of these codes.*
** *As required, based on watering strategy.*

Based on research conducted at the Greenhouse and Processing Crops Research Centre, Harrow, by AAFC and OMAFRA staff and at Vineland Research Station, Vineland Station, by OMAFRA staff.

Nitrogen (N)

This nutrient has the greatest impact on vegetative growth. High rates of nitrogen induce vigorous vegetative growth to the detriment of fruit production. However, under hot and bright conditions, the nitrogen level must be increased to enable the plant to continue growing and maximize its fruit production potential.

Too much nitrogen results in strong, thick stems; curled leaves in the head of the plant; big flower trusses and individual flowers; and poor fruit set. Symptoms of nitrogen deficiency include light-green foliage and pale yellow flowers with thin heads, resulting in hard plants.

Potassium (K)

Potassium greatly influences fruit quality and at high rates is also effective in hardening growth. Potassium levels are particularly critical at planting time to control subsequent growth and prevent ripening disorders. The ratio between potassium and nitrogen is also important: the higher the ratio, the slower the growth. Too little potassium results in fruit quality problems such as blotchy ripening, boxy fruit and green shoulders.

Phosphorus (P)

Phosphorus is used in much smaller quantities than nitrogen and potassium. Initially, phosphorus is important for early root growth and is strongly influenced by the temperature and pH of the growing media. At low temperatures, phosphorus uptake decreases. Similarly, it is not readily available to plants when pH levels are high. Phosphorus has a profound effect on both vegetative growth and fruit set. Deficiency symptoms include a characteristic purple colour of the leaf veins and the stem, thin growth and poor cluster development. Phosphorus toxicity is uncommon.

Magnesium (Mg)

Although magnesium deficiency is very common, it rarely results in yield reduction. Rather, it may affect fruit quality. Deficiency usually exists only in the plant and is related either to high potassium levels in the feed solution (resulting in a potassium-induced magnesium deficiency) or to poor root development, both of which make it difficult for the plant to take up enough magnesium. The plant is then forced to move magnesium from old leaves to new ones, leaving the older leaves chlorotic. A magnesium deficiency is easily corrected with Epsom salt sprays.

Calcium (Ca)

Calcium deficiency usually causes blossom end rot on fruit and dieback on growing tips. In most cases, it is caused by water stress due to inadequate or uneven watering, frequent and large variations in relative humidity, an imbalanced fertilizer program or high salt levels. Sprays of calcium nitrate or calcium chloride will help correct a calcium deficiency, but improving water balance in the plant is a more practical solution to the problem.

Sulphur (S)

Sulphur deficiency is rarely a problem since sulphur is present in many fertilizers. High sulphur levels can result in excessively high salts and can also reduce the uptake of molybdenum.

Iron (Fe)

Iron deficiency, a frequent problem, is usually observed as chlorosis in young leaves. In most cases, iron deficiencies are induced by high pH levels in the growing media, high levels of manganese, poor root growth or anaerobic conditions due to over-watering. Foliar sprays of iron salts or iron chelates are helpful, but the best solution is to eliminate the source of the problem.

Manganese (Mn)

Manganese deficiency is frequently confused with iron deficiency. Symptoms are interveinal chlorosis and light-green veins. As the deficiency symptoms become more severe, the interveinal chlorosis becomes more yellow and brown spots appear at the base of the leaflets. In most instances, however, brown spots indicate iron toxicity. Manganese toxicity can also be a problem and is encountered when media, especially soil, is pasteurized using steam but not subsequently leached.

Copper (Cu)

Copper levels may occasionally drop too low in peat media or in soilless culture if this element is not included in the fertilizer schedule. Symptoms are similar to high salt levels: dark-green younger leaves that frequently wilt, restricted plant growth, thinner stems and leaves and, as the severity increases, chlorosis and necrosis. As symptoms progress, the leaflet tips become necrotic and flower buds fail to develop.

Boron (B)

The symptoms of boron deficiency include brittle leaves, premature wilting and, in severe cases, dieback of the growing tips. It is easily corrected by spraying a borax solution on the leaves. The range between adequate boron levels and toxic levels is small, so use caution when applying borax sprays. Boron toxicity can cause severe plant damage.

Zinc (Zn)

This element is rarely deficient. In contrast, too much zinc can be toxic to plants. This is a potential problem in recirculating hydroponic systems if galvanized piping is used, since the nutrient solution reacts with the piping, releasing excessive quantities of zinc. Rainwater collected from newly erected greenhouses where the galvanized gutters have had no special treatments can also cause zinc toxicity.

Molybdenum (Mo)

Low pH conditions or high sulphur levels can induce molybdenum deficiency. Although symptoms of molybdenum deficiency are not easy to identify, leaf tissue analysis is a dependable diagnostic tool.

Harvesting and Storage

Harvest greenhouse tomato fruit with the calyx attached to help identify the product. Tomatoes should be harvested three times a week or every other day, especially during the summer, to ensure all fruit is picked at about the same stage of ripeness, when the fruit is turning from green to orange-red in colour. Some growers may harvest at the breaker stage (when the blossom end of the fruit is starting to show colour). Tomato fruit harvested at a more advanced stage of ripening has greater flavour but may have a shorter shelf life since it becomes over-ripe sooner.

Harvest manually by snapping or breaking the calyx at the knuckle (a natural break point on the flower stem). Cluster tomatoes are cut close to the stem using a knife or scissors. Place fruit in picking baskets or crates to prevent the calyx from puncturing neighbouring fruit. Clip the stem if necessary to minimize punctures when the fruit is handled during packing and at display counters. Fruit that is dropped will easily bruise, shortening its shelf life.

Pick tomatoes as early as possible in the morning while it is still cool. Move fruit to a covered area or directly to a cooler as quickly as possible, since fruit left in the greenhouse rapidly overheats and deteriorates. The packing facilities must be cooled (15°C) to maintain fruit quality. Pack uniformity (colour, size and quality) is critical to ensure good acceptance at the marketplace. Label all tomato fruit with a PLU or bar coding sticker during packing. Computerized colour sorters with weight- and size-grading packing lines and automatic labellers are commonly used to pack tomatoes.

If required, store fruit at 12°C after grading and packing. After removing the fruit from cold storage, take care to avoid condensation on the fruit by either moving it into a dry atmosphere or raising the fruit temperature gradually. Cooled trucks should be used to ship the fruit to the marketplace.

For updated fruit grade specifications and price structuring according to fruit grade, contact the Ontario Greenhouse Vegetable Growers at Box 417, Leamington, Ontario N8H 3W5 or call them at 519-326-2604.

6. Cucumber

The success of cucumber production in the greenhouse depends on the ability to maintain ideal conditions for growth. Cucumber plants are extremely sensitive to change. Optimizing the greenhouse environment — including light, temperature, humidity, air movement and the root environment (i.e., root temperature, moisture availability, nutrition, etc.) — produces high yield and quality. A tropical plant originating from the Indian subcontinent, the cucumber plant performs best when grown under high light, temperature, humidity, moisture and fertility conditions.

English cucumber is the principal commercial cucumber grown in the greenhouse. These seedless cucumbers are parthenocarpic, with flowers that do not require pollination for fruit formation. There is an increase in Ontario production of mini cucumbers, grown specifically for a niche market.

Cultivars

There is a wide selection of cultivars suitable for Ontario greenhouse growing conditions. Fruit quality, yield and plant habit vary between cultivars and seed companies. The marketplace demands fruit 32–42 cm long, with a diameter of 4 cm. A suitable cultivar should produce a high percentage of fruit that meet these criteria. Short cucumbers bring lower returns.

The use of the Powdery Mildew Tolerant (PMT) cultivars is increasing, and each seed company has a selection that may be suitable for Ontario growers. Tolerant or resistant cultivars have a slightly lower yield, making it more difficult to grow them economically. Earlier PMT cultivars produced short cucumbers, but the new cultivars produce more fruit of an acceptable size. Some greenhouse operations also grow mini-cucumbers or gherkin-type cucumbers for specific markets.

For more details on the individual cultivars, contact the OMAFRA greenhouse vegetable specialist or your seed supplier.

Cropping Schedule

Cucumber plants grow rapidly; depending on light and growing conditions, they can produce marketable fruit in 8–12 weeks. Several different cropping cycles can be used, with planting and termination dates adjusted based on the marketing schedule and light availability.

A two-crop cycle consists of:

1. a January planting, mid-February harvest and termination in mid-July or August
2. an August planting, end-of-September harvest and termination at the end of November or beginning of December

A three-crop production cycle, which maintains high fruit quality and market share, consists of:

1. a December planting with late-January to early-February harvest and termination in May
2. a second planting that follows immediately and terminates in August
3. a third planting that starts immediately after clean-up and is terminated in December

An increasing number of growers are now using a four-crop production cycle to remain at the marketplace longer with high-quality, premium fruit. This accomplished by using larger transplants, a shorter harvest period and four planting dates spaced out during the year. There is an increased interest in the use of artificial lights to produce cucumbers during the winter months. However, keep in mind that producing cucumbers during November, December and January has traditionally been financially successful only when market prices have been high, since the production is low and supplementary lights increase the costs of production.

Seeding

Seed may be sown directly into rockwool blocks or in flats filled with vermiculite. If the second approach is used, seedlings should be transplanted into rockwool blocks after they have emerged. Cucumber seed germination is rapid and requires timely transplanting into the blocks to minimize root damage. The optimum temperature for cucumber seed germination is 26–28°C.

Cucumber seedlings emerge 2–3 days after sowing and, if sown in flats, are ready for transplanting into blocks in 4–6 days.

Plant Raising

After transplanting, maintain a temperature of 23–25°C for 24 hours a day to encourage rapid root establishment. Subsequently, lower the temperature to 21°C at night and adjust the daytime temperature based on light intensity. To avoid impeding root development, it is very important to maintain the block temperature between 21–23°C and make sure the block is neither too wet nor too dry.

To maximize space efficiency, begin by placing the blocks close together and then increase the spacing when the leaves of neighbouring plants begin to touch. This maximizes light interception and helps maintain a sturdy, stocky plant. Supplementing natural light with high-pressure sodium lamps at 40 watts/m^2 for 24 hours improves plant quality and reduces the time required to reach the transplanting stage. Supplemental carbon dioxide (CO_2) (1,000 ppm on sunny days, 400 ppm on cloudy days or when using supplementary lights) helps achieve the desired plant in a shorter time.

A cucumber plant is ready for transplanting into the production houses when:

- 4–5 leaves have developed
- the plant is about 25–30 cm tall

To obtain a plant of this size, it must be staked *(Plate 31)*. Place a stake in the pot beside the plant and use elastic bands or metal rings to attach the plant to the stake. At transplanting time the staked plants will be less prone to damage during transport and will be easier to string up after planting them in the greenhouse.

Alternatively, plants can be moved into the production greenhouses at the 3–4 leaf stage. The advantage of moving the plants earlier include:

- decreasing the time required in the starter house
- allowing the use of smaller starter houses

Younger plants placed directly in the greenhouse require greater care to ensure proper root zone temperature and adequate moisture. Begin by placing the plants beside the opening in the rockwool bag and watering the plants with the drip irrigation system. Once they have 4–5 leaves or are 25–35 cm tall, they may be moved onto the opening, allowing the roots to grow into the slab.

Plant Spacing

In general, grow cucumber plants in twin growing rows with a walkway between each pair of rows. For a hot-water heating system, locate the heating pipes on the walkway; for a steam heating system, place them within the twin rows. Make the walkways 140–170 cm wide and the space between the twin rows 100–120 cm wide.

Plant spacing along the growing row varies, depending on the growing system used. In general, space plants at 0.55–0.74 m^2/plant or 1.4–1.8 plants/m^2. The larger spacing per plant:

- improves fruit quality, length and colour
- decreases costs, number of seeds and labour
- maintains a high yield (number of cucumbers/plant or cucumbers/m^2)

Growing Media

Rockwool and coco coir are the media most commonly used for Ontario cucumber production. A cucumber slab measures 20 cm wide × 7.5 cm high × 90–100 cm long. With a slab that is 90 cm long, use 2 plants/slab; with a slab that is 100 cm long, use 3 plants/slab. Space the slabs within the rows to provide the desired plant density. Using 3 plants/slab requires less growing media.

To spend even less on growing media, consider using the "V" system to grow plants. For this system, create a single growing row instead of two. Attach the plants from the single row to the twin overhead wires (tie the first plant to one overhead wire and the next plant to the other wire, and then repeat). This should form two rows of stems at the appropriate stem spacing (1.35–1.81 stems/m^2). This system lends itself well to recirculating the nutrient solution.

After placing the rockwool slabs, soak the bags using a nutrient solution with an electrical conductivity (EC) of 2.0–2.5 mS/cm and a pH of 5.8 (see *Rockwool Culture*, page 17). Immediately after planting, irrigate the crop with a complete nutrient solution (EC 2.0 mS/cm, pH 5.5) until the slabs are fully saturated. Shortly after planting, cut the bags to allow the excess solution to drain. For the next 2–3 days, water the plants only if it is sunny. After that, water according to plant requirements (see Chapter 3, page 19). Use a nutrient solution containing a higher (10%) calcium level from planting out until the plants reach the wire.

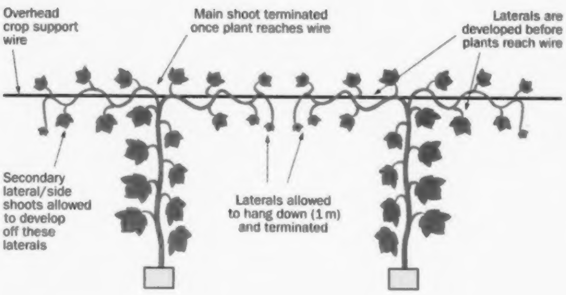
Crop Training

The modified umbrella system is commonly used in Ontario. Plants are trained along a twine that runs from the base of the plant to the overhead wire (1.9–2.0 m high). Once the plants reach the wire, there are two options.

System 1

Remove the growing point of the plant, allowing one leaf to remain over the wire. Develop 2 laterals 1–2 nodes below the wire. Attach them to the overhead wire using special hooks or by wrapping them around the wire. After these laterals have developed 3–4 nodes, let them grow down. Remove the growing point when the lateral is approximately halfway to the ground. Then allow another lateral at the wire to develop and train it in a similar fashion. After harvesting all the fruit from the first lateral, remove it to make room for the next lateral to develop. Repeat this process throughout the growing season. (See Figure 6–1, *Cucumber Pruning System 1.*)

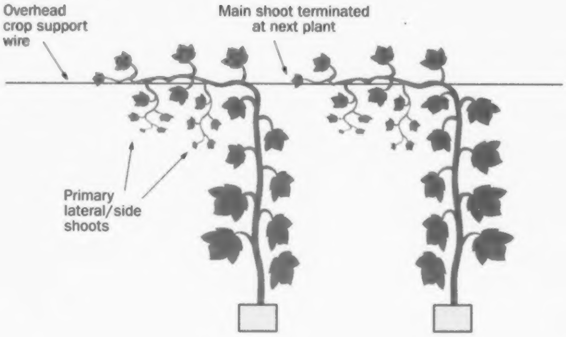
Figure 6–1. Cucumber Pruning System 1


Overhead crop support wire
Main shoot terminated once plant reaches wire
Laterals are developed before plants reach wire
Secondary lateral/side shoots allowed to develop off these laterals
Laterals allowed to hang down (1 m) and terminated

System 2

Train the main stem along the wire. When it reaches the neighbouring plant, pinch off the growing point and allow the laterals to develop at the 2nd and 4th nodes from the bend. Allow these laterals to hang down. Pinch them off when they are halfway to the ground, and then develop the next set of laterals from the main stem along the wire. Repeat this process throughout the growing season. (See Figure 6–2, *Cucumber Pruning System 2.*)

Figure 6–2. Cucumber Pruning System 2


Overhead crop support wire
Main shoot terminated at next plant
Primary lateral/side shoots

Once the basic framework is in place, subsequent pruning depends upon the vigour of the plants. For good fruit colour, make sure there is good light penetration. To achieve this, it may be necessary to:

- remove one or two healthy green leaves in a vegetative crop
- train laterals to grow downwards

During the season, remove the senescing (aging or dried out) leaves above the wire. Train a lateral over and along the wire so that it receives good light. This overhead lateral will continue to produce fruit and generate more laterals during the remainder of the season.

High-wire cucumber production is a new technique used by some growers (especially those growing mini-cucumbers or growing English cucumbers under supplementary lights). The plants are trained along the twine strung between the base of the plant and the overhead wire (2.0–3.0 m high). The plants are twisted or clipped to the twine and the lower leaves removed (similar to tomatoes) once a week to improve air circulation around the base of the plant and expose fruit for ease of harvest. Once the growing points reach the overhead wire, the plants are lowered. All lateral shoots are removed weekly, and a one-leaf lateral shoot is allowed to develop to improve the microclimate around the head of the plant. Removing the lower leaves also removes infected leaves, decreasing sources of disease infestation (especially powdery mildew).

Fruit Pruning

Pruning the fruit is necessary to ensure a proper balance between the number of leaves produced and the number of developing fruit. If the plant is too vegetative (i.e., has too many leaves), fruit set and harvest is delayed. In a fruitful crop, where there is too much fruit in relation to leaf area, young fruit take longer to mature and may become crooked or abort. This restricts new flower development and growth. A balanced plant maintains a steady production throughout the season, minimizing the rollercoaster effect of one week of high production followed by a week of low production. Use Table 6–1, *Fruit Load on Young Cucumber Plants* as a guide to balance the young cucumber plant.

On the main stem, allow only one fruit per alternate node to develop at a time. On the laterals, allow one fruit per node to develop. When using high-wire cucumber production, allow alternate node fruit development initially, when the plants are developing, and later at every node. The rate of fruit loading is determined by the light levels and the time of year, even when supplementary light is used.

Table 6–1. Fruit Load on Young Cucumber Plants

	Height of first fruit set or number of leaves before first fruit	**Number of fruit below the wire (2 m)**
Winter planting (Dec., Jan., Feb.)	90–100 cm OR 10–12 leaves	3–4
Spring/summer planting (Apr., May, Jun.)	80–90 cm OR 8–10 leaves	5–8
Late fall (Oct., Nov.)	90–100 cm OR 10–12 leaves	3–4

Climate

Temperature strongly influences the rate of development, fruit length, fruit colour and the balance between vegetative growth and fruit development (generative growth) of seedless cucumbers. Adjusting the 24-hour average temperature determines the rate of growth. The optimum 24-hour temperature for cucumbers is 21°C. Varying the difference between day and night temperature influences the plant morphology and alters the vegetative-to-generative balance (see Chapter 1, page 1).

In general, use an initial high 24-hour average temperature with little difference between day and night temperatures to ensure the plant establishes rapidly and reaches the overhead wire. This creates plants with thinner stems, longer internodes and widely spaced, slightly thinner and smaller leaves. Subsequently lower the night temperature to encourage development of thicker laterals and strong flowers, using plant appearance to determine the level and duration of the temperature drop. A lower temperature for a longer time will thicken the growing stem and leaves, while a higher temperature will thin them. (See Table 6–2, *Temperature Regime for Cucumber Production* and Table 6–3, *CUCUMBERS: Summary of Growing Recommendations,* page 52).

To minimize water condensation on the fruit, gradually raise the air temperature at the end of the night by 1°C/hr, achieving the daytime set temperature at least half an hour before sunrise. Avoid sharp changes in temperature, which result in dramatic changes in relative humidity (RH) and vapour pressure deficit (VPD).

Similarly, do not use a sharp increase in venting to quickly lower the temperature or relative humidity. The fruit may suffer from chilling injury, curl or abort. A VPD between 0.4–0.8 kPa minimizes the chance of condensation and maintains an actively transpiring plant.

Cucumber plants grow rapidly. A mature, fruit-bearing plant may use up to 3–4 L of water per plant per day in the summer. Apply a complete nutrient solution at all times. In rockwool culture, as many as 30 irrigation cycles a day may be required. See Table 6–4, *Fertigation Schedule for Cucumber,* page 52 and Table 6–5, *Weights of Fertilizer Required to Make Stock Nutrient Solutions,* page 53 for a suggested fertilizer schedule for greenhouse cucumber production.

Applying a higher-EC solution increases fruit quality and shelf life. Avoid excessive application of the nutrient solution to the root zone because saturation of the media increases the incidence of Pythium root rots. Start watering 1–2 hours after sunrise and end 1–2 hours before sunset to allow the root zone to aerate during the night. Night watering may be necessary on cold winter nights when the demand for heat is high and the greenhouse RH is low, or on extremely sunny, dry days in the spring and summer. Overwatering a crop produces soft stem growth prone to diseases such as Botrytis grey mould, gummy stem blight or Penicillium rot. See Table 6–3, *CUCUMBERS: Summary of Growing Recommendations,* page 52 for a summary of growing recommendations.

Table 6–2. Temperature Regime for Cucumber Production

	Day	Night	Vent*
After transplanting (3–4 days) (°C)	23–25	23–25	None
Growth to wire (3 weeks) (°C)	23–25	21–23	increase by 2
Until first lateral harvested/picked (°C)	23	21	increase by 2
Remainder of season (°C)**	23	17–21	increase by 2

* *Increase vent temperature setting by the amount indicated to allow vents to open.*

** *Within the night temperature range specified, set the temperature based on the type of plant growth desired. A warmer night will result in thinner plants and rapid fruit development; a cooler night will result in a thicker plant, strong lateral growth and flower development and slower plant growth.*

Harvesting and Storage

Cucumber fruit reaches harvesting size 10–14 days after flowering, depending on factors such as the cultivar, light, temperature, moisture and nutrition.

The minimum marketable size is 28 cm long with a 4-cm diameter. Cut the fruit from the plant cleanly at the fruit stalk to allow the wound to heal rapidly and decrease the risk of disease. Do not break off the fruit by twisting it. To prevent fruit from becoming over-mature, harvest cucumbers every other day. Daily harvest may be necessary in some weeks in the summer when fruit growth is rapid.

Seedless cucumbers have a skin that provides little resistance to desiccation, so they lose water very rapidly. Shrink-wrapping the fruit extends the shelf life and allows a PLU or bar-coded label to be attached. Contact the Ontario Greenhouse Vegetable Growers for grade specifications and label requirements.

Store harvested cucumbers at 13°C away from drafts. The fruit is extremely sensitive to ethylene: as little as 0.5 ppm of ethylene causes cucumbers to yellow, so do not place cucumbers in storage facilities or transport them with ethylene-producing fruit such as apples, tomatoes, etc.

Table 6–3. CUCUMBERS: Summary of Growing Recommendations

	Germination	Plant Raising	Transplanting	Harvesting Stage	Full Harvest
Temperature*					
day (°C)	27–28	24	23–25	23	23
night (°C)	27–28	21	23–25	21	17–21
Solution EC (mS/cm)	0–1.0	1.0–2.5	2.0–2.5	2.5–3.0	2.1–2.8
Solution pH	—	5.8	5.8	5.8	5.8
Vol. of nutrient solution (L/day)**	—	0.2–0.3	0.2–0.3	1.0–1.5	1.5–2.5
Feed schedule***	—	A	B	C	D

* *Use lower settings when light is low.*

** *As required based on watering strategy.*

*** *See Table 6–4,* Fertigation Schedule for Cucumber *for an explanation of these codes.*

Based on research conducted at the Greenhouse and Processing Crops Research Centre, Harrow, by AAFC and OMAFRA staff and at Vineland Research Station, Vineland Station by OMAFRA staff.

Table 6–4. Fertigation Schedule for Cucumber (ppm nutrient)

	N	NH_4	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo	S*	Cl*	HCO_3
A. Slab saturation	200	10	50	253	247	75	0.8	0.55	0.33	0.5	0.05	0.05	120	0	25
B. For 4–6 wks after planting	180	10	50	370	210	75	0.8	0.55	0.33	0.5	0.05	0.05	120	0	25
C. Normal feed	190	22	50	370	190	65	0.8	0.55	0.33	0.5	0.05	0.05	120	0	25
D. Heavy fruit load	210	22	50	370	190	75	0.8	0.55	0.33	0.5	0.05	0.05	120	0	25

* *The fertilizers selected to create the nutrient solution will determine the final level of these anions.*

Based on research conducted at the Greenhouse and Processing Crops Research Centre, Harrow, by AAFC and OMAFRA staff and at Vineland Research Station, Vineland Station by OMAFRA staff.

Table 6–5. Weights of Fertilizer Required to Make Stock Nutrient Solutions (requires 1:100 dilution to make the final solution)

Fertilizer	**A***	**B***	**C***	**D***
	kg/1,000 L (Dilution ratio 1:100)			
Calcium nitrate	112.11	92.67	82.11	82.11
Potassium nitrate	25.72	31.5	40.89	56.27
Monopotassium phosphate	6.75	6.75	6.75	6.75
Potassium sulphate	25.77	44.05	37.19	25.95
Magnesium sulphate	66.0	66.0	66.0	66.0
Ammonium nitrate	0.0	4.0	8.0	8.0
	g/1,000 L (Dilution 1:100)			
Iron chelate 13%	407.69	407.69	407.69	407.69
Manganese sulphate	165.38	165.38	165.38	165.38
Zinc sulphate	91.43	91.43	91.43	91.43
Borax	246.67	246.67	246.67	246.67
Copper sulphate	16.0	16.0	16.0	16.0
Sodium molybdate	10.87	10.87	10.87	10.87
Desired EC (mS/cm)	2.5–3.0	2.5–3.0	2.0–3.0	2.5–3.5
Desired pH	5.8	5.8	5.8	5.8
Vol. of water (L)**	0.25–0.5	0.5–1.0	2.0–3.0	2.0–3.0

* *See Table 6–4,* Fertigation Schedule for Cucumber *for an explanation of these codes.*

** *As required, based on watering strategy*

Based on research conducted at the Greenhouse and Processing Crops Research Centre, Harrow, by AAFC and OMAFRA staff and at Vineland Research Station, Vineland Station by OMAFRA staff.

7. Pepper

Greenhouse-grown sweet peppers have increased in popularity with the Ontario consumer over the past few years, resulting in more area devoted to pepper production than cucumbers. These include red-, yellow- or orange-coloured fruit — and, to a smaller extent, purple fruit — that are harvested when fully mature. There is also increased interest in greenhouse-grown mature green peppers, especially with the development of several new cultivars that remain green at maturity.

Cultivars

Select cultivars based on yield potential; fruit size, shape and quality; plant habit; vigour; popularity of colour in the marketplace; and tolerance to diseases, especially to virus-borne diseases. The most commonly grown type is the large, blocky, mainly red pepper.

Contact the OMAFRA greenhouse vegetable specialist or your seed company for more details on cultivars.

Cropping Schedule

Since peppers are very slow growing, use a year-round greenhouse pepper schedule. Typically, sow seeds in early October, transplant into the greenhouse in early December and harvest the first fruit beginning mid-March and ending late November/early December.

Producing peppers over the winter for harvest during December, January and February is not recommended without supplemental lighting, since ambient light levels are too low to sustain an economic yield. Supplemental high-pressure sodium lighting is not being used in Ontario, since the yield increase is currently not enough to offset the increased cost.

Seeding

Use high-quality seed from a reputable seed company. Soak rockwool plugs thoroughly with either plain water or a complete nutrient solution at pH 5.8 and electrical conductivity (EC) 1.0 mS/cm. Sow the seed. After sowing, cover the plugs with medium vermiculite, rewet them and place them directly into germination chambers or cover them with a 2-mil clear poly sheet and then place them on benches with bottom heat. The optimum germination temperature is 25–26°C. Once emergence occurs (after 3–4 days), remove the plugs from the germination chamber or remove the poly coverings, and then reduce the temperature to 23°C. Transplant the seedlings once the cotyledon leaves are fully expanded and the true leaves have begun to emerge (approximately 14–18 days after sowing).

Plant Raising

Soak the rockwool blocks (10 × 10 × 7.5 cm) with a complete nutrient solution (EC 1.5– 2.0 mS/cm, pH 5.2), and then place the seedlings directly into the hole. They can be placed straight up or bent at 90° like a hockey stick. More operations now use the hockey-stick technique to increase stability of the plant in the rockwood block. Next, put vermiculite at the base of the stem to provide support.

During this phase, the optimum night temperature is 20°C and the day temperature is 21–23°C. (Use the higher day temperature when the day is sunny or when a higher rate of growth is desired.) Apply a complete nutrient solution to the transplants as necessary (see Chapter 4, page 31).

Carbon dioxide supplementation (700–800 ppm) and supplementary high-pressure sodium lighting at 40 watts/m^2 greatly improves transplant vigour and size, as well as decreases the time required to attain an ideal transplant by 1–2 weeks. Pepper plants are ready for transplanting when the first flower bud (king flower) is clearly visible or about to open at the first branch. This usually occurs 6–8 weeks after sowing *(Plate 32)*.

Plant Spacing

Initially during the seedling stage, place the blocks close together to conserve space. As the young plants grow, space the blocks further apart to a final spacing of 18 plants/m^2 before transplanting them into the greenhouse.

In the greenhouse, a plant density of 3–3.5 plants/m^2 is optimal because plants are normally trained as a 2-stemmed plant, resulting in 6–7 stems/m^2. Arrange the greenhouse plants as twin growing rows with 0.6 m between growing rows and 0.9 m-wide walkways. Adjust plant spacing within the row to obtain the desired plant density. Most growers now opt for the "V" system, where 95–100-cm bags with 6 plants per bag result in a density of 6.9–6.6 stems/m^2 (see Chapter 3, page 18). Space the stems to obtain the desired plant density and train the stems to allow maximum light interception.

Growing Media

In Ontario, most pepper acreage is grown in rockwool or coco peat (coir). Soak the growing media with the complete nutrient solution at pH 5.2 and EC 2.0 mS/cm. After transplanting, use a nutrient solution with a suggested pH of 5.2 and an EC of 2.0–2.5 mS/cm. Adjust the EC based on the rate of plant growth and the amount of available light. If the EC is too low, the plants will be weaker and more susceptible to disease. An EC that is too high restricts growth, resulting in shorter internodes, thinner-stemmed plants and small, thin leaves. Make sure the canopy is not too limited, because fruit exposed to sunlight may be damaged by sunscald *(Plates 33, 34).*

Managing moisture levels in the transplant blocks is important to reduce the accumulation of salts at the base of the plant, which can cause elephant's foot *(Plate 35).* This damaged area may be the entry point for stem rot diseases such as Fusarium stem rot. During the production cycle, use a nutrient solution with a pH of 5.2–5.5 and an EC ranging from 2.0–3.0 mS/cm. Maintain a slab pH of 5.8 and an EC of 2.5–3.5 mS/cm (see *Rockwool Culture,* page 17). To lower the EC, increase the amount of water applied, but keep in mind that too much water may be detrimental to root development. To increase the EC, decrease the amount of water applied, keeping in mind that this may lead to blossom end rot.

Apply a nutrient solution at 18–22°C as shown in Table 7–1, *Fertigation Schedule for Peppers* and Table 7–2, *Weights of Fertilizer Required to Make Stock Nutrient Solutions.* Begin irrigation 1–2 hours after sunrise and end 1–2 hours before sunset. Night watering may be required, especially when the heat demand is high on cold, windy nights and/or the relative humidity is low in the greenhouse.

Pruning and Training

By nature, pepper plants are multi-stemmed. Young plants branch after several weeks' growth, usually about the 6th–8th leaf stage. Subsequently, a flower bud and a lateral branch or side shoot develop at every node. Remove these to create a 2-stemmed plant

Table 7–1. Fertigation Schedule for Peppers (ppm nutrient)

	N	NH$_4$	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo	S*	Cl*	HCO$_3$
A. Slab saturation	200	10	50	253	247	75	0.8	0.55	0.33	0.5	0.05	0.05	100–150	50	25
B. For 4–6 weeks after planting	180	10	50	370	190	75	0.8	0.55	0.33	0.5	0.05	0.05	100–150	50	25
C. Normal feed	190	22	50	370	190	65	0.8	0.55	0.33	0.5	0.05	0.05	100–150	50	25
D. Heavy fruit load	210	22	50	370	190	75	0.8	0.55	0.33	0.5	0.05	0.05	100–150	50	25

* *The fertilizers selected to create the nutrient solution will determine the final level of these anions.*

Based on research conducted at the Greenhouse and Processing Crops Research Centre, Harrow, by AAFC and OMAFRA staff and at Vineland Research Station, Vineland Station, by OMAFRA staff.

Table 7–2. Weights of Fertilizer Required to Make Stock Nutrient Solutions (requires 1:100 dilution to make the final solution)

Fertilizer	A*	B*	C*	D*
	kg/1,000 L (Dilution ratio 1:100)			
Calcium nitrate	112.11	82.11	82.11	82.11
Potassium nitrate	25.72	42.43	40.89	56.27
Monopotassium phosphate	6.75	6.75	6.75	6.75
Potassium sulphate	25.77	36.06	37.19	25.95
Magnesium sulphate	66.0	66.0	56.0	66.0
Ammonium nitrate	0.0	1.0	8.0	8.0
	g/1,000 L (Dilution 1:100)			
Iron chelate 13%	407.69	407.69	407.69	407.69
Manganese sulphate	165.78	165.78	165.78	165.78
Zinc sulphate	91.43	91.43	91.43	91.43
Borax	246.67	246.67	246.67	246.67
Copper sulphate	16.0	16.0	16.0	16.0
Sodium molybdate	10.87	10.87	10.87	10.87
Desired EC (mS/cm)	2.5–3.0	3.0–3.5	2.5–3.5	2.5–3.5
Desired pH	5.2–5.8	5.2–5.8	5.2–5.8	5.2–5.8
Vol. of water (L)**	0.25–0.50	0.5–1.0	1.0–2.0	1.5–2.5

* *See Table 7–1,* Fertigation Schedule for Peppers *for an explanation of these codes.*

** *As required, based on watering strategy.*

Based on research conducted at the Greenhouse and Processing Crops Research Centre, Harrow, by AAFC and OMAFRA staff and at Vineland Research Station, Vineland Station, by OMAFRA staff.

(about 2 weeks after transplanting). Remove the lateral branches or side shoots by snapping them or cutting them off with a sharp knife. Conduct this process every 10–14 days. Do not allow flowers to set until the 2nd or 3rd node after the initial branching. Remove the flowers by hand or by adjusting the greenhouse temperature (see *Climate*, page 58). To encourage a larger plant to develop, do not allow the king flower to develop into a fruit.

In certain situations, side shoots should be allowed to develop. To increase leaf area, the side shoot may be trimmed to allow one leaf to develop. This can also prevent sunscald (see *Climate*, page 58). In some cases, a flower at the 1st node of the side shoot can be left to develop into a fruit to help ensure fruit development at all levels (nodes), especially if the flower at the main stem node does not develop.

Pepper plants must be supported with twine that is tied at the base of the plant using a loose, non-slip knot and attached to the overhead wires 3.7–4.6 m above. Twist the twine around the plant in a loose spiral every 10–14 days. In greenhouse operations without high wires, peppers can be grown by layering the plants in a fashion similar to tomatoes (see Chapter 5, page 38). This will result in lower yield than the traditional high-wire production system.

Climate

By nature, peppers are slow growing. They require a high temperature and a balanced fertility program to maintain a reasonable growth rate. Fruit quality and yield are determined by the ability to develop large, well-shaped flowers on strongly growing plants. Flowers formed on weak plants are usually smaller and poorly coloured and tend to drop off or, if they develop into fruit, the fruit are smaller and poorly shaped. Improper pollination resulting in poor seed set also produces misshapen fruit.

After transplanting peppers onto the slabs, maintain air temperatures of 23°C during the day and 21°C at night for 1 week to promote strong vegetative growth and rapid root establishment. This initial temperature regime discourages fruit set and results in a better-balanced plant (see *Fruit Set,* below). Approximately 7–10 days after transplanting, gradually lower the night temperature to 18–20°C to encourage strong flowers and good fruit set. To balance the ratio of leaf area to fruit, manipulate the night temperature to adjust flower development and fruit set. A lower night temperature encourages generative growth (flowering), whereas a high night temperature encourages vegetative growth.

A ventilation temperature 2–3°C above the heating set point is generally recommended but may be adjusted to maintain optimum relative humidity (RH). A vapour pressure deficit (VPD) of 0.4–0.7 kPa is recommended. At the suggested growing temperature, this results in an RH of 70–80%. In the early planting stages, the RH may be too low, making it necessary to use a temporary 2-mil clear poly as a humidity/thermal screen above the crop to raise the RH. Alternatively, fogging or misting the greenhouse also raises the RH. However, excessive RH increases the risk of disease.

Maintaining continuous fruit setting on pepper plants is difficult to accomplish. Grow peppers in greenhouses that have good climate controls and are at least 4.5 m high. While a well-designed forced air heating system (i.e., one with a heat delivery system in between the growing rows) may be used, it must be monitored and adjusted frequently to maintain the right conditions.

Maintaining ideal conditions during periods of high temperature and light allows the plant to develop a good canopy, minimizing blossom end rot (BER) and sunscald. During the summer, screening or shading is necessary. Using a movable screen or shade curtain (especially in glass greenhouses) that is activated when light and temperature levels are high decreases stress to the pepper plants. Another option is to whitewash the greenhouse roof. Apply a low-level whitewash in late April or early May and a second coat in early-to-mid June. In late August remove the whitewash to maximize light penetration in the fall.

In addition, allow a flag leaf to develop by terminating the lateral branch once a single leaf has developed. This will improve the microclimate around the growing point as well as increase shade to protect the developing fruit from sunscald. (See Table 7–3, *PEPPERS: Summary of Growing Recommendations*)

Fruit Set

Pepper plants tend to flower at every node and set fruit in flushes of about 4 fruits per stem. Flowers on the following 2–3 nodes will abort, and then the plant will set fruit again. Manipulating the greenhouse environment to improve plant balance minimizes the gap between flushes. Removing flowers and/or poor-quality fruit is also helpful in balancing the plant and ensuring a steady harvest.

Remove any flowers set below the 2nd or 3rd node early in their development. This ensures the plant has enough leaf area to sustain the developing fruit load without decreasing the rate of growth and fruit development. Too early a fruit set results in small, poorly shaped fruit and increased susceptibility to BER.

Harvesting and Storage

Harvest greenhouse peppers when more than 80% of their colour is present. Green-coloured peppers are harvested when they reach maturity, as indicated by good fruit size and a change in the hue of green. The highest financial return is obtained when harvested peppers are fully coloured. Harvesting fruit too early delays full colour and shortens the shelf life.

Harvest peppers by cutting the fruit stalk with a small, sharp knife. A clean, smooth cut decreases the risk of disease pathogens entering the plant and gives the harvested fruit a pleasant appearance. Cut all fruit stalk stubs flush with the main stem. This encourages rapid healing and reduces diseases such as Fusarium stem and fruit rot, or Botrytis grey mould.

Fruit is graded to size and colour to ensure an attractive and uniform product. If necessary, store peppers at 7–8°C. Ethylene released from fruit and vegetables stored with peppers may cause pepper fruit to overripen, decreasing shelf life and marketability.

Table 7–3. PEPPERS: Summary of Growing Recommendations

	Germination	Plant Raising	Transplanting	Harvest Stage	Full Harvest
Temperature*					
day (°C)	25	21–23	24	21–24	21–23
night (°C)	25	20–21	21	18–21	17–18
Solution EC (mS/cm)	0.0–1.0	1.0–2.0	1.5–2.5	2.0–3.0	2.0–3.0
Solution pH	5.2–5.8	5.2–5.8	5.2–5.8	5.2–5.8	5.2–5.8
Vol. of nutrient solution (L/day)**	—	0.2–0.3	0.2–0.3	0.5–1.5	1.5–2.0
Feed schedule***	—	A	B	C	D

* *Use lower settings when light level is low.*
** *As required, based on watering strategy.*
*** *See Table 7–1,* Fertigation Schedule for Peppers *for an explanation of these codes.*

Based on research conducted at the Greenhouse and Processing Crops Research Centre, Harrow, by AAFC and OMAFRA staff and at Vineland Research Station, Vineland Station, by OMAFRA staff.

8. Lettuce

Most commercial greenhouse lettuce is grown hydroponically. Soil production was popular in the past, especially following a spring, soil-grown tomato crop. This kept staff busy and provided extra cash. However, a shift towards monoculture and hydroponic tomato production ended this practice. At present, lettuce production is conducted exclusively as a single operation.

Greenhouse lettuce is primarily marketed to niche markets such as upscale restaurants and fruit and vegetable markets, although increasingly more product is being shipped to supermarkets.

To provide an average of 1,000 heads of lettuce per week, a growing area of 325 m^2 is required. The average operation size is 2,500 m^2, with the majority of production conducted in Nutrient Film Technique (NFT) culture. In this system, plants are grown in a recirculated, continuously flowing film of nutrient solution.

Successful marketing of greenhouse lettuce requires a system designed to provide a continuous supply. This is accomplished with a 2-stage production system that consists of:

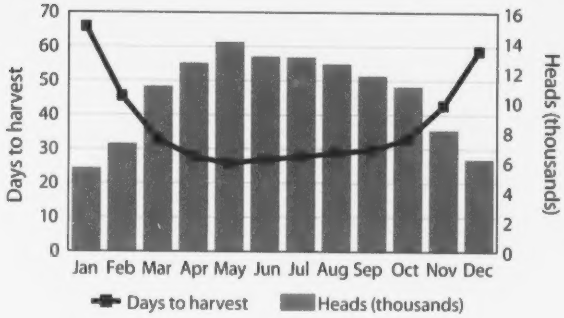
- a plant-raising section where weekly seeding is conducted and transplants are raised
- a production section where transplants are grown to maturity and harvested

A total of 8–10 production cycles per year are possible (see Figure 8–1, *Lettuce Yield Projection for Southwestern Ontario*).

Cultivars

Currently, the butterhead — known as Boston or Bibb lettuce — is the main type of greenhouse lettuce. It forms a loose head consisting of small tender leaves surrounded by larger outer leaves, rather than a tight head. For more details on cultivars, contact the OMAFRA greenhouse vegetable specialist or your seed company.

Figure 8–1. Lettuce Yield Projection for Southwestern Ontario



Seeding

Fill the flats with a peat-perlite mixture and soak it with plain water at 18°C before sowing to prevent disturbing the seed distribution. Sow seeds in flats by placing seed on the media surface and covering it with a shallow layer of fine peat. Cover the flats with 2-mil clear poly to keep moisture in the media. A germination temperature of 15–18°C is optimal. Lettuce seed may not germinate if the temperature is too high, especially in summer. Decrease the temperature by shading the germination area or using misting systems.

In some cases, seed can be sown directly into the OASIS or rockwool mini-blocks or forestry seedling compressed peat discs. For OASIS or rockwool mini-blocks, use a similar procedure to the process of seeding flats described above. In the case of compressed peat discs, place the discs in a flat and soak with them tap water. Once the discs are fully swollen, place lettuce seeds in the openings at the top.

Plant Raising

After the first true leaves emerge (7–10 days), select the best seedlings from the flat and transplant them to OASIS or rockwool mini-blocks (3 × 3 × 3 cm). Water the seedlings with a dilute complete nutrient solution (electrical conductivity 1.0–1.5 mS/cm, pH 6.0) using overhead misting or sub-irrigation. Once the seedlings reach the desired size, place the plugs in NFT troughs. Similarly, blocks with direct-sown seed are placed in the NFT troughs when the seedlings have reached the desired size.

Maintain a temperature of 15–18°C and use supplementary high-pressure sodium lighting at 40 watts/m^2 (24-hour photoperiod) and carbon dioxide (CO_2) at 1,000 ppm. Especially under low light levels in winter and on cloudy days, the 24-hour photoperiod enhances plant growth and decreases time to transplanting.

Move young plants to permanent troughs after 3–4 leaves emerge (usually 3–4 weeks after sowing). Depending upon the seasonal solar radiation, growing temperature and CO_2 supplementation, harvesting can begin 4–8 weeks later. During summer, the time between sowing to harvest can be as short as 7–8 weeks, while in the winter it may be as long as 11–12 weeks.

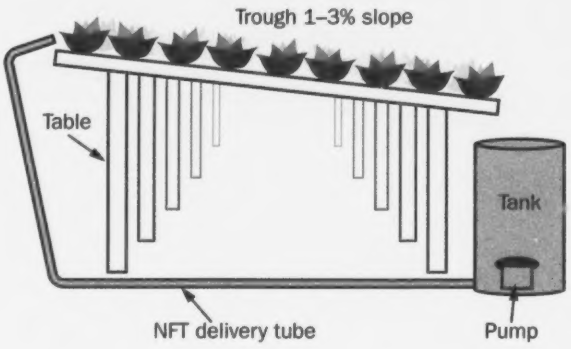
Plant Spacing

To maximize efficiency, adjust plant spacing according to plant age/size. In the early stages of production, plants are grown close together (10 cm × 10 cm or 100 cm^2 spacing). When neighbouring leaves touch, move the plants further apart (20 cm × 20 cm or 400 cm^2) and maintain this spacing until harvest.

Crop Production

There are numerous NFT trough systems designed for lettuce production. These range from a simple 10-cm PVC drainage pipe or eavestrough to extruded troughs with a channeled floor and built-in plant supports. In all cases, the trough provides a channel for the recirculating nutrient solution and a support for the placement of the transplant (usually a cover through which the transplant is placed). The trough must be rigid enough to be moved in order to adjust plant spacing as the plants grow, as well as be disinfected between crop cycles (Figure 8–2, *NFT Layout for Lettuce*).

Figure 8–2. NFT Layout for Lettuce



Aeration of the root system is important: the system must be designed to provide a shallow film of fast-flowing nutrient solution. If the film is too deep, a greater number of roots are submerged, resulting in poorly aerated roots that are weak, brown in colour, easily broken and prone to microbial infection.

Aerate the nutrient solution in the mixing tanks by using a small pump that recirculates the solution back into the mixing tank via an overhead showerhead-type structure. An aerator — a device that increases the air in the solution as it is pumped back into the reservoir tank — can also be used. Design the return line and the reservoir tank so that the return water splashes into the reservoir tank, increasing aeration and mixing.

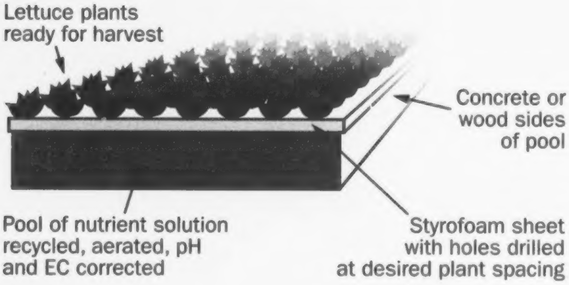
The mixing tank or reservoir should have a capacity of 1,000–1,500 L/1,000 m^2 to ensure a large enough reserve of solution while still providing a rapid response to electrical conductivity (EC) and pH adjustments. A reservoir tank that is too large may not respond rapidly to automatic additions of fertilizer and acid during production. EC and pH levels should be controlled automatically to ensure optimal EC and pH ranges and to decrease EC fluctuations that promote tip burn. The EC level of the nutrient solution should be adjusted depending upon the time of year, stage of crop production, cultivar and rate of growth. Table

8–1, *Fertigation Schedule for NFT Lettuce,* page 64 and Table 8–2, *Weights of Fertilizer Required to Make Stock Nutrient Solutions,* page 64 provide a fertilizer schedule for lettuce production.

An alternative production system for greenhouse lettuce is the floating culture (Figure 8–3, *Floating Raft Production System*). This method uses styrofoam sheets with holes drilled at specified plant densities that are floated in pools of nutrient solution. The pools themselves can take a number of forms, including:

- 5 × 15 cm pressure-treated lumber designed like a backyard hockey rink, lined with plastic
- engineered concrete pools 30 cm deep that run the length and width of the greenhouse
- ebb-and-flow tables altered to maintain a nutrient solution depth of 3–5 cm

Figure 8–3. Floating Raft Production System


Lettuce plants ready for harvest
Concrete or wood sides of pool
Pool of nutrient solution recycled, aerated, pH and EC corrected
Styrofoam sheet with holes drilled at desired plant spacing

The nutrient solution is recirculated, aerated and amended with fertilizers and acids to maintain the desired nutrient solution composition. The length and width of the pools can be varied to fit the space available in the greenhouse or may be determined by the materials used. This system produces very successful crops.

Climate

Temperature regimes for the cropping cycle should be adjusted depending on seasonal solar radiation, the cultivar, the desired rate of growth and the harvest date. In general, maintain night temperatures of 15–18°C with a light-dependent day temperature of 18–19°C (cloudy days) to 19–22°C (sunny days). Begin venting when the temperature rises 1–2°C above the set point. Adjust the temperature regimes to maintain the weekly production goal, but be sure that any temperature changes are gradual to prevent disease or lettuce tip burn.

Lettuce can be grown as a cool crop (10°C at night and 15–18°C during the day), especially during the winter when light levels are low. However, this extends the time from planting to harvest. Keep relative humidity (RH) between 75–85% or vapour pressure deficit (VPD) between 0.4–0.8 kPa. During the summer, when outside temperatures are high, do everything possible to keep a lower greenhouse temperature, since high temperatures reduce lettuce leaf/head quality.

Shade the greenhouses by using moveable shade curtains or applying whitewash to the outer greenhouse structure, and use fan and pad cooling systems or high-pressure fogging systems to keep temperatures cool. Avoid conditions that result in free water on the leaves or low transpiration rates.

Use supplemental high-pressure sodium lighting (>40 watts/m^2) during the winter and during periods of cloudy weather to obtain an 18-hour photoperiod. Keep CO_2 levels at 1,000 ppm whenever natural or artificial light is present.

Harvesting and Storage

Once the lettuce has reached a marketable size (250 g), remove it from the trough with the roots attached and place it, roots first, in a poly bag. Tie off the roots with an elastic band, but leave the bag open around the head of lettuce. Special clear plastic clamshell containers with a small trough for the roots are also available. Lettuce harvested without the roots should be bagged bottom first and the top left open. Place the bagged lettuce in boxes containing 12–18 heads for shipping.

If lettuce is improperly stored, its quality deteriorates rapidly. Lettuce should be stored at 2–4°C and high RH (80–90%). Freezing temperatures damage the product, while high temperatures result in further leaf development, reducing customer appeal. Store lettuce away from ethylene-producing products, since ethylene injury causes brown spots at the veins (see *Russet Spot,* page 88).

Table 8–1. Fertigation Schedule for NFT Lettuce (ppm nutrient)

	N	NH_4	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo	S	Cl	HCO_3
All stages	200	10	50	400	200	55	6	1	0.5	0.5	0.05	0.05	120	100	25

Based on research conducted at the Greenhouse and Processing Crops Research Centre, Harrow, by AAFC and OMAFRA staff and at Vineland Research Station, Vineland Station by OMAFRA staff.

Table 8–2. Weights of Fertilizer Required to Make Stock Nutrient Solutions (requires 1:100 dilution to make the final solution)

Fertilizer	kg/1,000 L (Dilution 1:100)
Calcium nitrate	87.37
Potassium nitrate	52.56
Monopotassium phosphate	6.75
Potassium sulphate	20.41
Potassium chloride	14.17
Magnesium sulphate	4.6
Ammonium nitrate	0.74
	g/1,000 L (Dilution 1:100)
Iron chelate 13%	4,620.0
Manganese sulphate	380.77
Zinc sulphate	142.86
Borax	326.67
Copper sulphate	16.0
Sodium molybdate	10.87
Desired EC (mS/cm)	2.2–3.0
Desired pH	6.2–6.5
Vol. of water (L)	N/A

Based on research conducted at the Greenhouse and Processing Crops Research Centre, Harrow, by AAFC and OMAFRA staff and at Vineland Research Station, Vineland Station by OMAFRA staff.

9. Eggplant

Eggplants are a new crop in Ontario greenhouses and are being grown for niche markets. Like tomatoes and peppers, eggplants are from the Solanaceae family and perform well under similar growing conditions. The fruit may vary from the traditional large globe or pear shape to a long cylindrical shape. The colour may range from a dark purple that is almost black to lighter purples to completely white. Some fruit have a combination of purple and white stripes.

Cultivars

Select cultivars based on the yield, fruit size, shape and colour desired by the marketplace. Select cultivars that have a good growing habit, disease tolerances and resistance and few or no prickles. Select a rootstock (usually tomato) that suits the type of greenhouse and growing schedule.

For more details on cultivars, contact the OMAFRA greenhouse vegetable specialist or your seed company.

Cropping Schedule

Eggplants are grown for one season (either a long crop or a short crop). See Table 9–1, *Long Crop Schedule for Eggplant.* Most growers will graft when growing a long crop and adjust the sowing dates for the rootstock to produce a rootstock stem diameter that is similar to the stem diameter of the desired plant (scions).

Seeding

Soak rockwool plugs with plain water or a complete nutrient solution with pH 5.8 and electrical conductivity (EC) 1.0 mS/cm. Sow seeds in the plugs. After sowing, cover the seed with medium vermiculite, soak the plugs and then place them in a germination chamber. Alternatively, cover them with a 2-mil clear poly sheet and place them on a bench. The optimum germination temperature for eggplant is 25–26°C. Eggplant seedlings will emerge 6–8 days after sowing and are ready to be transplanted into transplant blocks 3–4 days later.

Plant Raising

After transplanting, maintain a 19–22°C day temperature and an 18–19°C night temperature. On sunny days the temperature may be allowed to increase 1–2°C. Water plants when the block has lost 50% of its weight, re-wetting until the block is saturated (see Chapter 3, page 19). Use a complete nutrient solution with EC 2.5–3.5mS/cm and pH 5.5 at all times. The volume and the EC of the nutrient solution should be determined by the light, temperature and vapour pressure deficit (VPD) in the greenhouse, as well as the size of the transplant (see Chapter 3, page 19). The plant is ready to be moved to the production facility when it has reached a height of 25–30 cm.

Table 9–1. Long-Crop Schedule for Eggplant

Crop Type	Sow	Plant	First Harvest	Terminate
All year	Late November to early December	Mid-January to the end of January	Mid-March to the end of March	Late November to early December

Plant Spacing

Eggplants are spaced at 2.7 plants/m^2 with 2–3 stems per plant, resulting in 5–8 stems per square metre. Eggplant stems are not flexible, making them more difficult to lower. Extra stems should be allowed to develop to decrease plant height.

Growing Media

Rockwool and coco coir are the most commonly used growing media. Before planting, soak the growing media with a solution of pH 5.8 and EC 2.5 mS/cm. After planting, gradually increase the EC of the nutrient solution to 3.0mS/cm. On subsequent irrigations, adjust the EC of the nutrient solution based on the time of the year, light levels, outside climate conditions, the size of the plant, the desired appearance and the rate of plant growth, as well as the greenhouse temperature and VPD (see Chapter 3, page 19). The same factors should be used to determine the volume of solution applied. Maintain a growing media EC between 2.5–3.5 mS/cm by adjusting the percent leach.

Pruning and Training

Support the plants with twine that is tied at the base of the plant attached to an overhead wire 3–3.5 m above. Twist the stem around the twine or use support clips to attach the plant to the twine every 10–14 days. Allow multi-stems to develop after 12–14 leaf nodes and allow flowers to develop in the leaf axil *(Plate 36).* At least one flower develops at each node, but quite often several flowers can be present. In the case of the larger eggplant cultivars, remove the extra flowers. To increase the productivity of smaller-fruited cultivars, allow all flowers to develop.

Climate

The greenhouse environment for eggplants should be similar to that for tomatoes. Balance the plant between vegetative and generative phase with temperature and VPD manipulations similar to those for tomato. This will maintain stem head development and flower size — an essential consideration for maximizing fruit quantity and quality. In the early stage, maintain a more even temperature regimen of 22°C during the day and 19°C during the night. As fruit load increases, set a lower night temperature of 17–19°C. See Table 9–2, *EGGPLANTS: Summary of Growing Recommendations* for more details.

Fruit Set

Eggplant flowers are self-pollinating *(Plate 37).* The rate of flower and fruit development is determined by the size of the flower, the fruit load and the balance between vegetative and generative growth. A larger flower on a balanced plant will produce a harvestable fruit faster (4–6 weeks) compared to a small flower on a vegetative plant. To help maintain a balanced, fast-flowering plant, manipulate the greenhouse temperature and the VPD based on light levels (again, similar to a tomato regime).

Harvesting and Storage

Eggplant fruit is ready to harvest once the colour at the blossom end starts to lighten (on the larger cultivars) or when the desired market size has been attained. A daily harvest ensures a higher percentage of high-quality, uniform fruit. Cut off the fruit using a small sharp knife. A clean cut decreases the risk of disease incidence.

Move harvested fruit from the greenhouse to the header house or packing area as soon as possible to prevent the fruit from heating up too much. Note that dark-coloured fruit will absorb more energy from the sunlight and must be covered after harvest to maintain fruit quality.

Eggplant fruit can be stored at 12–15°C to prolong shelf life. Minimize water condensation on the fruit during shipping and storage.

Table 9–2. EGGPLANTS: Summary of Growing Recommendations

	Germination	Plant Raising	Transplanting	Harvesting Stage	Full Harvest
Temperature*					
day (°C)	25	19–22	24	22	20–22
night (°C)	25	18–19	24	19	17–19
Solution EC (mS/cm)	0.0–1.0	2.5–3.5	2.5–3.5	2.5–3.5	2.5–3.5
Solution pH	5.8	5.8	5.8	5.8	5.8
Vol. of nutrient solution (L/day)**	—	0.2–0.3	0.2–0.3	0.5–1.5	1.5–2.5
Fertilizer schedule	—	Similar to tomato			

* *Use lower settings when the light level is low.*

** *As required, based on watering strategy.*

This table is based on research conducted at the Greenhouse and Processing Crops Research Centre, Harrow, by AAFC and OMAFRA staff.

10. Integrated Disease Management

Proper integration of disease prevention practices into the total crop management plan is critical to plant health within any greenhouse production system and the profitability of any business.

At a minimum, the basic objectives of any program should be to:

- **reduce the possibility of introducing diseases into the crop**
- **avoid creating conditions conducive to disease establishment and spread**

A sound disease management program for any greenhouse crop integrates a few universal principles and concepts into the overall production system for that particular greenhouse crop.

It is important to understand those concepts, and the strategies developed from them, in order to make modifications appropriate for a particular greenhouse or crop situation. A disease control program involves more than a fungicide spray or drench schedule for the various crops grown. Too often, fungicide applications address the symptoms, not the problem.

The Disease-Triangle Concept

Three factors are necessary for disease development:

- a pathogen or disease-causing organism (e.g., a fungus, bacterium or virus)
- a susceptible plant for the pathogen to infect
- an environment that encourages the pathogen to infect the plant

For example, *Pythium* spp. will attack seedlings when the rooting medium is cool (15–17°C) and wet, the plant density is very high and the sanitation is generally poor.

The environment includes both the soil or media environment in which the roots grow and the above-ground environment where shoots, leaves, flowers and fruits are produced. Characteristics of the growing media environment that must be considered include pH, nutrient levels and their balance, electrical conductivity (EC), moisture-holding capacity, drainage and oxygen content. Characteristics of the above-ground environment that must be considered include light levels, temperature, air movement, relative humidity and air quality.

Six Principles for Plant Disease Management

Exclusion

One of the primary goals of disease management is preventing pathogens from becoming established in the greenhouse. To exclude disease pathogens from operations, use sanitation measures such as having visitors step through disinfecting footbaths and wear gloves and coveralls. Using soil-free media such as rockwool will also minimize the incidence of soil-borne pathogens.

Avoidance

Use practices to avoid situations that promote disease development. For example, use heating and venting to avoid plant wetness — a condition that can favour the development of Botrytis grey mould.

Resistance

Different cultivars have differing abilities to remain healthy or resist attack when a pathogen is present and/or the environment is conducive to pathogen development. For example, most new tomato cultivars have genetic resistance to Fusarium crown and root rot and tobacco mosaic virus.

Protection/Prevention

Fungicides can be applied before any disease is observed. These often protect crops when conditions are conducive to disease development. Disinfecting gloved hands can reduce transmission of viral-borne infections such as pepper mild mottle virus in peppers.

Eradication

Steam pasteurization of growing media can eliminate root-borne diseases and nematodes. Sanitizing products can effectively reduce the number of bacteria or fungal spores in dust, on the surfaces of benches, in or on irrigation lines and emitters and on tools used for propagation or production.

Therapy

In the case of fungal attacks, treat infected plants to slow further sporulation and spread of the fungus. For example, fungicides sprayed on cucumbers suppress powdery mildew. Refer to OMAFRA Publication 835, *Crop Protection Guide for Greenhouse Vegetables* for other information on disease control.

Basic Integrated Disease Control Strategies

Environmental Manipulation

Environmental manipulation includes controlling air temperature, relative humidity (RH), light levels and air circulation, as well as media composition, pH, EC and water content. To create a healthy greenhouse environment:

- Understand the conditions required for the optimum growth of the crop and for the common diseases of that crop.
- Avoid extremes or, more importantly, rapid changes in relative humidity to reduce disease incidence.
- Be aware that temperatures of leaf surfaces can be lower than air temperatures due to radiant heat losses.
- Provide good air circulation. Poor air circulation can cause uneven temperatures through the crop. It can also lead to free moisture forming on the plants, particularly at night, creating ideal conditions for mildew and *Didymella* infections.
- Avoid all extremes as much as possible. For example, over-fertilization promotes *Fusarium solani* in peppers, while the combination of very high or low temperatures and overwatering favours the development of *Pythium.*

Modification of Cultural Practices

Continually stressing plants makes them more susceptible to attack by disease pathogens. Plants are stressed when the root and/or shoot environments do not favour normal, healthy growth. To avoid plant stress:

- Understand the growing requirements of the crops being produced. Provide the appropriate conditions for the crops.
- Maintain recommended EC and percentage drain for optimal root development.
- Maintain sanitary conditions at all stages of production to minimize sources of inoculum.
- Ensure that crop maintenance practices are completed sufficiently early in the day to allow wounds to dry, making them less prone to infection.
- If foliar diseases are an ongoing problem, review temperature, relative humidity, air circulation patterns and watering practices. The incidence of foliar diseases can often be reduced by maintaining higher night temperatures or higher minimum pipe temperatures, along with proper venting.

Sanitation and Roguing

Sanitation is the first step in any disease management program. If a source of infection is constantly present due to poor hygiene, disease management programs will be expensive and less successful. Carry out good sanitation practices as the first line of defence in the greenhouse and adjoining structures (boiler rooms, etc.) in the immediate vicinity of the greenhouse and during every stage of crop production.

Proper greenhouse sanitation is a continual, year-round process. **Cleanliness on its own may not totally avoid disease problems, but it is a basic component of any disease management program.** It is important to:

- Clean and then disinfect empty structures, heating pipes, walks, benches or equipment to ensure they don't harbour disease organisms that could infect the next crop. Be sure to use a disinfectant that is appropriate for the task.

- Use footbaths between greenhouse compartments. Routine maintenance of these footbaths is essential. Follow the instructions on the label of the product being used.
- Remove dead and dying plants. Place them in bags when removing them from the growing row.
- Place rogued plants in commercial garbage containers and dispose of them in a landfill to reduce potential sources of inoculum.
- Dedicate specific wheelbarrows or carts for transporting diseased material, and don't use them for other purposes. If this is not possible, disinfect them after every use.
- Have employees wear disposable gloves when handling diseased plant material. At a minimum, employees should wash their hands thoroughly with soap or bactericidal hand lotion before performing another function. Note that hand washing is not as effective as using disposable gloves.
- Keep normal crop residues well away and downwind from the greenhouse to prevent particles of media or plant tissue from being blown or sucked into the greenhouse. Cover plant residues immediately. If this is not possible, move residues off-site on a routine basis to a landfill or composting site.
- Keep walks and all surfaces as clean as possible.
- Carefully check both the foliage and roots of transplants for disease. Monitor any suspect seedlings closely.
- Maintain good drainage to eliminate puddles and wet surfaces, since these provide ideal breeding sites for fungus gnats and shoreflies. These insect pests can carry root diseases such as Pythium and Fusarium root rots.
- Keep the greenhouse and immediate surroundings free of weeds and ornamentals that may harbour diseases like Pepino mosaic virus (PepMV), beet pseudo-yellows virus (BPYV) and cucumber mosaic virus (CMV) or insects that can carry disease.
- For soil-grown crops, steam the soil before planting winter crops to minimize the carryover of root and crown rot pathogens.
- Dip cutting knives in disinfectant between plants or at least at the end of each row to prevent the spread of disease.
- Between crops, perform a general cleaning and disinfection of the greenhouse structure, heating pipes, walks, benches and all harvesting equipment.
- Avoid overwintering garden or house plants in the greenhouse, since they can harbour pests that will infect the next crop.
- Use a heat treatment to remove pest infestations when the greenhouse is empty between crops. Maintain temperatures at about 40°C and humidity at less than 50% for 3–4 days to control insect and mite pests. This is particularly easy to accomplish during the warmer months, when these temperatures can be achieved by simply closing the vents. Note that at higher temperatures, plastic fittings may warp.

See also OMAFRA Factsheet *Sanitation Recommendations for Management of Insect and Mite Pests of Greenhouse Vegetables*, Order No. 94-029.

Cleaning and Disinfecting

Disinfection is the removal of disease-causing organisms from surfaces of the greenhouse and the accompanying equipment and tools. It is a crucial step in the general cleanup at the end of the season, minimizing carryover of disease-causing organisms to subsequent crops. To disinfect properly, keep the following points in mind:

- At the end of a crop cycle, consider cleaning horizontal surfaces such as rafters and the tops of overhead piping where dust and debris can collect and later fall on produce during production. Before washing, remove all equipment used in harvesting fruit to ensure that dirty water does not fall on such equipment and possibly contaminate it. Use a power washer to clean the surfaces, and then let the water drain and the area air-dry completely before moving fruit-harvesting equipment back into the greenhouse.
- Remove all organic matter and inorganic deposits (including calcium deposits) from all surfaces and objects to be disinfected, including lines, drip stakes, etc. Any organic matter or residues present will react with the disinfectant and reduce its effectiveness. Scrub textured surfaces with a detergent or commercial-grade cleaner and a power washer. If

acid is used to remove calcium deposits, rinse the lines before using disinfectants to avoid chemical reactions and the production of dangerous gases.

- Do not use hard water (water with calcium ions in excess of 300–400 ppm) with disinfectants because it destroys the disinfecting ability of certain chemicals.
- Ideally, mix disinfectants in warm water (approximately 20°C) and apply the solution to dry surfaces during the evening in a warm greenhouse. In general, lower temperatures require longer contact times between the disinfectant and surfaces, whereas higher temperatures increase efficiency two- to three-fold for every 10°C rise in temperature.
- Always use the proper concentration of disinfectant as recommended by the product manufacturer. Concentrations that are too weak may not disinfect properly, while concentrations that are too strong may damage the materials that the disinfectant contacts.

Carefully read labels for all disinfectants before use, follow all safety precautions (particularly in terms of protective wear) and consult the product distributor for advice on the most efficient use of these products.

Pathogen-Free Plant Material

Do not bring new plants into the greenhouse until the old crop has been moved out and the area thoroughly disinfected. Alternatively, isolate the new plants in a separate area. Such isolation is not possible when interplanting a crop, but try to minimize contact between the new and old crops.

Vector Control

Many viruses are spread by insects. For example, aphids spread cucumber mosaic virus in cucumbers and thrips can spread TSWV/INSV in tomatoes and peppers.

Consider screening vents to reduce the number of insect pests that enter the greenhouse. This can make biocontrol programs easier by generally suppressing pest population levels and by excluding larger pests such as cabbage loopers and lygus bugs (see OMAFRA Factsheet *Screening of Greenhouses for Insect Exclusion,* Order No. 00-021).

Fungus gnats can spread the spores of *Pythium*. The larvae damage young roots by feeding on them. Research has shown that *Pythium* oospores (thick-walled sexual spores) are routinely transmitted through the gut of fungus gnat larvae. As well, the adult can transfer the pathogen with its legs and mouthparts.

Controlling algae growth and providing adequate drainage also helps control insect populations and minimize the spread of pathogens.

Resistant Cultivars

Many commercially available cultivars are resistant to diseases. For example, many tomato cultivars are resistant to Fusarium crown and root rot, as well as several other fungal and viral diseases, while several cucumber cultivars are available that have different levels of tolerance to powdery mildew.

Chemical Control

Fungicides have been the conventional approach to managing fungal diseases. Their role varies from protecting healthy plants to treating infected plants and eradicating diseases. To reduce the likelihood of resistance developing, rotate among fungicides with different modes of action (see OMAFRA Publication 835, *Crop Protection Guide for Greenhouse Vegetables* on control of other diseases).

Biological Control

Biological control of diseases involves the use of beneficial fungi and bacteria that strongly suppress disease-causing organisms without harming the crop. Mechanisms of action include competition, antibiosis, parasitism or induced resistance. Most biocontrol products should be considered preventative and their use started with the planting of a crop.

Several microbial fungicides are registered in Canada for use on greenhouse crops for suppressing root and foliar diseases (see OMAFRA Publication 835, *Crop Protection Guide for Greenhouse Vegetables*). For example, Mycostop is registered for the control of damping off, root and stem rot, and wilt caused by *Fusarium, Pythium* and *Phytophthora.* The active ingredient is the soil bacterium *Streptomyces griseovirdis,* which kills fungi by parasitizing the pathogen and living off its nutrients, as well as producing antibiotics. Because the effect is preventive, Mycostop is best used as early as possible in the crop's life and repeated according to the label instructions.

Rootshield provides protection by colonizing the surface of the roots and root rhizophere, using waste products produced during normal root growth. It also parasitizes disease-causing fungi by releasing enzymes that break down their cell walls. Apply the product soon after germination and/or transplanting. Two formulations are available: a granular formulation that can be incorporated into the growing media or a drench to be applied to newly transplanted seedlings.

Most microbial biocontrols suppress pathogens, rather than completely eliminate them, and must be integrated with other management strategies for optimum results.

Success Criteria

To manage diseases as effectively as possible, greenhouse operators should:

- Emphasize prevention rather than cure.
- Monitor crops at least weekly and enlist workers in the early detection of unusual symptoms.
- Walk the crop(s) to detect problems early. This means checking the crop foliage, root systems and environmental conditions.
- Keep detailed records using a system that an merge cultural, environmental and insect and disase data in order to analyze trends.
- Include weather data in these detailed records to help anticipate potential disease problems. For example, a cool, cloudy and wet summer without proper climate management (heating and venting to manage RH) creates ideal conditions for many diseases such as downy mildew, late blight, gummy stem blight, Botrytis grey mould, etc.
- Correctly diagnose diseases in order to determine how to manage the disease effectively. Soil-borne fungi are the most difficult pathogen for growers to identify. Send samples to the Pest Diagnostic Clinic, University of Guelph, for accurate diagnosis (see Appendix B). Contact the OMAFRA Greenhouse Vegetable Specialist or Greenhouse Vegetable IPM Specialist for further details. For some diseases, ELISA disease diagnostic kits for grower use are available from some local distributors.
- Develop a thorough understanding of the diseases that affect the crops being grown. Correct use and timing of management strategies then become part of an ongoing process.
- Because disease pathogens are microscopic, learn to anticipate when possible pathogen infection periods are likely to occur. By the time the problem is visible, the pathogen has usually been present for some time and is more difficult to control.

11. Diseases

As discussed in previous chapters, many diseases can be minimized by paying close attention to the growing conditions in the greenhouse, implementing good sanitation and hygiene measures and following proper cultural practices, such as nutrition and pruning. The result will be rapid-growing, well-balanced and healthy plants that produce high-quality fruit.

Plate 38 is an example of a situation that easily leads to disease outbreaks. Improper greenhouse climate management has allowed the formation of free water on the cucumber leaves, greatly increasing the risk of infection.

When outbreaks do occur, early recognition of greenhouse diseases and quick intervention can prevent or minimize financial losses. This chapter lists the main diseases affecting each crop and provides specific strategies for preventing or treating them.

Tomato

Tomato Diseases Caused by Fungi

Corky Root Rot (Pyrenochaeta lycopersici)

Infected plants show a lack of vigour (thin heads) and wilt or flag on sunny days. Light-brown lesions appear on the root surface early in the course of the disease. These are closer to the base of the plant in older roots. On larger and older roots, dry, brown, swollen corky lesions are visible. The corky layer peels off easily, revealing the vascular root tissue (stele). This is commonly known as "rat-tail." As the disease progresses, foliar chlorosis (yellow-brown chlorosis on the lower leaves) and more severe wilting are visible.

Corky root is a slow disease that takes a long time to kill the plant. That is why crop management is so important. Encouraging aggressive root systems — where new roots are continuously developing — minimizes problems associated with the disease. Do not plant in cold media.

In rockwool culture, the infected plant eventually infects the companion plant in the bag. At the end of the season, discard this bag, since steam sterilization may not be able to penetrate the large infected roots where the pathogen is located.

Damping-Off and Late Damping-Off (Pythium *and* Rhizoctonia)

Early damping-off decays the seed or seedling before it emerges. Given the wide use of hydroponic culture, with its inorganic growing media and seed treatment, this disease is not a common problem today.

Late damping-off results in the base of the seedling narrowing and collapsing, causing seedlings to topple *(Plate 39)*.

Minimize the problem by:

- ensuring sanitary conditions during seed sowing
- maintaining ideal media temperatures
- watering with warm water (18–22°C)
- using sterile growing media
- using clean water (avoid soil-contaminated water from wells or creeks) or disinfecting water if it is not clean
- using well-drained media
- watering the seedlings in the morning so the leaves and stems are dry before nightfall
- keeping a clean starter house and sowing bench

Fusarium Wilt and Verticillium Wilt (Fusarium *spp. and* Verticillium *spp.*)

Initial symptoms are a yellowing of the lower leaves and wilting. The yellowing begins in the older leaves and results in epinasty, where the leaves and growing tips bend downwards. In most cases the interveinal tissue turns a bright yellow, with brown-to-orange marks on the leaves. A brown discoloration in the vascular tissue extends high up the plant. In severely affected plants, leaf petioles may also exhibit vascular discoloration. It is best to minimize incidence of these wilts by using resistant cultivars and maintaining clean growing conditions.

Fusarium Crown and Root Rot **(Fusarium oxysporum f. sp. radicis-lycopersici *or FORL*)**

Plants infected with this disease wilt on sunny days and have a thin head, flaccid leaves and weak flowers. First symptoms are usually seen when plants are under high stress and heavily loaded with fruit, at the 6–8 cluster development stage. A chocolate-brown discoloration is usually visible at the base of the plant and ground level, and the roots are brown. Cutting open the stem base vertically reveals a chocolate-brown discoloration of the vascular tissue that extends 5–25 cm above ground level *(Plate 40).*

Most modern tomato cultivars have resistance to FORL. However, some desirable cultivars do not. If cultivars are used from this group, consider grafting them onto a resistant rootstock.

Grey Mould (Ghost Spot) **(Botrytis cinerea)**

This common disease affects all aerial parts of the plant and is prevalent in greenhouses where the environment and crop management are not optimal and especially where wounds or pruning cuts have not healed properly.

In most cases, the classical brown lesion is readily seen, often with concentric banding and grey fungal growth *(Plate 41).* On the stem, early symptoms are elliptical water-soaked lesions from which the mouldy, grey growth develops. Early leaf symptoms typically begin at a point of injury. This can be a result of:

- damage caused by workers when working the crop
- guttation (exudation of moisture) from the leaf edges or tips, usually when relative humidity (RH) is high, vapour pressure deficit (VPD) is low and root pressure is high
- a poor greenhouse environment that allows free moisture to be present on the plant

As the disease progresses, a grey mould covers the whole leaf. The fruit develops "ghost spot" — a light-coloured circular mark with a whitish-brown pinpoint in the middle *(Plate 42).*

Botrytis cinerea may infect the plant early in its life cycle (in the starter house or shortly after transplanting), but may not manifest itself until the plant is undergoing stress. This usually occurs prior to picking, 6–8 weeks after infection has occurred. However, the typical grey fungal growth may not become visible until as much as 12 weeks after initial infection.

Improving the greenhouse environment and cultural practices will decrease the incidence of *Botrytis cinerea.* Management of the disease includes:

- increasing heating and venting to prevent free water on the plants
- lowering the RH or raising the VPD
- raising the electrical conductivity (EC) of the nutrient solution
- adjusting water management strategies to prevent overwatering
- deleafing early in the day, allowing wounds to dry before nightfall

Infected stem tissue may be cut out to halt further development of the infection and prevent girdling, which results from complete invasion of the stem tissue and causes death.

Leaf Mould **(Fulvia fulva, *syn.* Cladosporium fulvum)**

The first symptoms of leaf mould are poorly defined yellowish-green areas on the upper surfaces of lower leaves. These symptoms are very similar to severe magnesium deficiency. However, leaf mould is accompanied by purplish, velvety fungal growth on the leaf underside that does not occur with magnesium deficiency. Leaf mould spreads rapidly under humid conditions and quickly moves towards the top of the plants.

Modern greenhouse tomato cultivars are resistant to this pathogen. Despite this, it is best to maintain ideal greenhouse conditions to prevent high disease pressure, which could result in the breakdown of resistance.

Powdery Mildew **(Oidium neolycopesici)**

This disease can occur as early as the seedling stage. Early symptoms are yellow spots or blotches on upper leaf surfaces, with white, powdery growth on the undersurface. In severe infestation, these lesions coalesce to create a white, powdery fungal growth on the leaf surface and stem *(Plates 43, 4).*

Powdery mildew spreads very rapidly under the conditions that are optimal for tomato production. At the first sign of this disease, treat the whole crop to minimize long-term problems.

Late Blight (Phytophthora infestans)

Early symptoms of this disease consist of irregular, dark, water-soaked areas, usually at the tips or edges of the lower leaves. Under favourable conditions, these areas enlarge rapidly, becoming brownish and paper-like *(Plate 45).* When humidity levels are high, a white fungal growth appears at the border of the lesions on the undersides of the leaves. As the disease progresses, the entire leaf, and eventually the whole plant, becomes infected and dies. Fruit symptoms consist of dark, "greasy" spots, which enlarge as the disease progresses *(Plate 46).* An infected plant can rot and die within a few days under continuously wet, cool conditions. Dry conditions keep the fungus in check and prevent the growth of mould on the undersides of the leaves. However, if humidity levels increase, the disease will become active again.

The fungus usually overwinters in potato and tomato plant material left in fields or cull piles. Other potential sources of infection include infected fruit and transplants. Spores from infected tissue are easily spread by wind to infect other plant hosts. Development of this disease depends on temperature and humidity levels. The fungus thrives when the nights are cool and days are warm. It produces abundant spores when the relative humidity is at or close to 100% and temperatures range between 16°C and 22°C. Spores require free water or dew to infect a plant but lose their viability in 3–6 hours if the relative humidity stays below 80%. However, once the fungus has penetrated the plant tissue, it develops very rapidly at 17–21°C. Temperatures above 30°C stop the growth of the fungus but do not kill it.

This disease can be successfully suppressed by using a combination of sanitation, good control of the environment and application of fungicides. Remove and destroy the infected plants, tissue and fruits. Heat and vent the greenhouse to keep humidity levels low. Maintain a vapour pressure deficit between 0.5–0.8 kPa to prevent dew formation and maintain good growing conditions. Regular applications of a fungicide are also needed to prevent infection of new growth and seedlings. Thorough coverage of the crop is very important.

Tomato Diseases Caused by Bacteria

Bacterial Canker (Clavibacter michiganensis *ssp.* michiganensis)

This is a very contagious and destructive disease of greenhouse tomato crops. The first symptom is usually a wilting of the upper leaves (typically one-sided wilting) followed by areas of dead or dying tissue on lower leaves *(Plate 47).* Additionally, the fruit may develop a whitish, mottled colour, instead of the normal green colour *(Plate 48).* Diseased fruit often drop off prematurely, especially if the plant is given a sharp shake. Inconspicuous, yellowish pustules or lesions that may occur on the surface of the stems and leaves in infected field tomato plants may not appear or be visible on greenhouse-grown plants. Such pustules contain many bacteria that are easily transferred by workers from diseased to healthy plants. It is important to recognize canker at an early stage and to remove infected plants before a major epidemic occurs.

Isolation is the best management technique to curb the spread of this disease:

- Place infected plants and the three to four neighbouring plants on either side in garbage bags and either incinerate or bury them.
- Workers who remove the infected plants must shower and change into clean clothes before re-entering the greenhouse.
- Restrict access to the row(s) from which the diseased plants were removed. Allow only selected personnel to enter the row(s) with infected plants, and assign one person to perform all work in this row. This person must wear coveralls to be used exclusively while working the infected row.
- Limit work in the diseased row(s) to the end of the day to minimize risk of disease transfer.
- Assign equipment, such as picking carts and boxes/crates, specifically for the infected row(s), or disinfect them before moving them into other areas of the greenhouse.

Sanitize the greenhouse and all equipment properly at the end of the crop to minimize the risk of disease recurrence.

Bacterial Stem Rot (Erwinia *and* Pseudomonas *spp.*)

The first symptom of bacterial stem rot is the sudden wilting of a few plants scattered throughout the greenhouse. The stems of the affected plants will be hollow (about 20–40 cm above the ground), will have a foul odour and may be filled with decaying plant tissue. In some cases, a dark chocolate-brown discoloration may be seen at the nodes. Infected plants tend to be soft, vigorous plants and primarily found in gutter rows where condensate drips. Infection usually occurs through a wound where a sucker, leaf or cluster has been removed *(Plate 49)*.

To curb this disease, alter the greenhouse environment by:

- increasing the VPD or lowering RH
- preventing water from condensing on the plants
- reducing the plant vigour by increasing the EC, reducing water application and/or reducing nitrogen levels
- keeping plants dry

This disease is usually seen in poorly managed crop and greenhouse environments.

Bacterial Wilt (Ralstonia solancearum)

Ralstonia solancearum is a serious bacterial soil-borne pathogen that causes wilting and death in solanaceous crops such as tomato, potato, tobacco and eggplant. Peppers grown in the field are not as susceptible as these other crops, unless they are grown under tropical or subtropical conditions.

Symptoms of this disease include wilting, browning of the vascular tissues in the lower parts of the stem, yellowing and streaking of the stem and development of adventitious roots at the base of stems. Note that *Ralstonia solancearum* can be present in healthy tissue without creating symptoms until a later date (latent infection), making early detection based on symptoms difficult. Have any suspect plants tested at a diagnostic clinic (see Appendix D).

Infection normally takes place through the roots and is easily spread via recirculating systems if the re-circulating water is not disinfected. Bacterial wilt can also spread on infected plant material, although local spread within the greenhouse is usually due to water moving through the growing media or splashing. Plant-to-plant spread may also occur if the root system of healthy plants comes in contact with those of infected plants. The disease can also be spread via infected tools and contaminated clothing or hands. It is not airborne but can survive in waterways.

Managing this disease consists primarily of quarantine and sanitation measures. Since it is a systemic disease, it is very difficult to control any other way.

While bacterial wilt or southern bacterial wilt caused by *Ralstonia solancearum* is not present in Canada at this time, it has occasionally been introduced into floriculture greenhouses and field tomatoes on contaminated seedlings from southern and tropical countries. There are five races and five biovars of *R. solancearum.* The term "race" is based on host range, while "biovar" is based on its biochemical reactions. *Ralstonia solancearum* Race 3 Biovar 2 is a regulated, quarantineable pathogen in Canada, Europe and the U.S. It is has also been placed on the USDA's 2002 *Agricultural Bioterrorism* "Select Agents and Toxins" list.

Due to the survival ability of this pathogen under temperate conditions and its threat to the tomato and potato industries, any plants diagnosed with Race 3 of *Ralstonia solancearum* must be reported to and disposed of by the Canadian Food Inspection Agency (CFIA).

Race 3 is of special concern to the potato industry in Canada and the U.S. because it can survive in soil in temperate regions and has caused severe losses in potato crops in other temperate countries. Race 3 is most severe between 24–35°C (its optimal temperature is 27°C) and decreases in virulence when temperatures exceed 35°C or fall below 10°C. Race 1 is endemic in the U.S., particularly in the southern parts where it causes severe damage to field-grown tomatoes. All the other races are not usually found outside the world's tropical and subtropical regions.

Tomato Diseases Caused by Viruses

Cucumber Mosaic Virus (Shoestring)

This virus produces narrow, spindly, mottled leaves on the upper portions of tomato plants. Infection is common when aphids and other insects move into the greenhouse, carrying the virus from outdoor cucumber or melon crops, beans, alfalfa or a number of symptomless carrier weed species. Infected plants may not die, but they rarely produce a marketable crop.

Remove infected plants to minimize further spread of the infection, and control pests. Keep areas within and around the greenhouse weed-free to reduce the source of the virus.

Pepino Mosaic Virus

Symptoms of this viral disease are more readily seen under low light and temperature conditions. During warmer, brighter months, older plants may harbour the virus but not show any symptoms. Symptoms usually appear 2–3 weeks after infection and tend to spread along the row. Plants infected with this disease can display various symptoms: fern-like leaf growth, a yellow-and-green mosaic pattern on the leaves, interveinal yellowing that resembles magnesium deficiency *(Plates 50, 51, 52)*, necrotic spots, browning of the stem and calyx and uneven fruit ripening. Crops affected by Pepino mosaic virus (PepMV) include tomato, potato, eggplant, tobacco and their relatives. Pepper is not yet known to be a host.

Pepino mosaic is *very contagious and easily spread* mechanically via plant sap on shoes and clothing, direct plant-to-plant contact and propagation (grafting, cuttings).

Pepino mosaic virus can be spread over long distances via the sap in infected fruits and survives for about 4 days on clothing and shoes. In moist organic debris held at 10°C, the virus remains stable and capable of infection for 4–5 weeks.

Management strategies for this disease are based on biosecurity concepts and include:

- limiting access by visitors, particularly those from other greenhouse operations
- practising general sanitation measures such as the use of footbaths, gloves and coveralls
- disinfecting footwear before entering and after leaving greenhouse operations
- marking off affected areas of the greenhouse to ensure that workers do not move from infected to non-infected rows
- changing clothes and thoroughly washing hands after working in a contaminated area and before moving into a non-infected area
- disinfecting all crates, carts and tools
- dipping gloved hands and tools (if used) in a disinfectant between plants
- using vegetative varieties or cultural measures such as grafting that promote plant vigour
- removing weeds and ornamentals from inside and around the greenhouse since some of these may be hosts of this virus
- disposing of infected crop residues by burying, burning or composting them, rather than disposing them in fields surrounding greenhouses, since this could serve as a source of re-infection for susceptible crops and weeds and, ultimately, the greenhouse crop itself

See also management procedures for *Bacterial Canker*, page 77.

Tomato Mosaic Virus and Tobacco Mosaic Virus

Tomato mosaic virus (ToMV) and tobacco mosaic virus (TMV) were problematic until the development of resistant cultivars. Although both viruses can infect tomato, ToMV tends to be restricted to tomatoes and TMV to tobacco. Other plant species that can be infected by these two viruses include pepper, tobacco, petunia, snapdragon and many weeds. At least five strains of ToMV exist. Symptoms caused by ToMV and TMV are very similar and depend on the virus strain, cultivar, age of the plant, temperature and light conditions. They could include wilting; mottling or green/yellow mosaic of leaves; fern-like leaves; stunted growth; blotchy, distorted fruits; internal browning of the fruit wall; and abortion of flowers and developing fruits.

Sources of these viruses include seeds, infected tobacco products, plant debris, soil and weeds. Plants can also be infected via damaged roots exposed to contaminated nutrient solutions. These viruses spread very rapidly by infected plants rubbing against healthy ones and by contaminated hands, tools and clothing. They are not normally spread by insects. ToMV and TMV are very persistent and can survive for a few years in plant residues in the soil, as well as on stored, unwashed clothing.

Using resistant cultivars is the best approach for managing this disease. If susceptible cultivars are used, do not allow workers to smoke in the greenhouse. Ensure that smokers wash and disinfect their hands before re-entering the greenhouse. In the event of an infection, carry out the management practices outlined for Pepino mosaic virus on page 79.

Tomato Spotted Wilt Virus and Impatiens Necrotic Spot Virus

Both tomato spotted wilt virus (TSWV) and impatiens necrotic spot virus (INSV) are very similar in biology and are both spread by western flower thrips. Unlike INSV, TSWV can also be vectored by seven other species of thrips. Thrips provide the most important means of transmission, but TSWV can also be transmitted by seeds.

These viruses have a wide host range and are generally similar. However, the recorded hosts of INSV appear to be fewer, and this virus is more frequently found on ornamental crops than on vegetables. Susceptible hosts include tomato, pepper, eggplant, lettuce, cucumber, cauliflower, tobacco, chrysanthemum, petunia and many weeds.

Symptoms of both diseases vary and include bronzing, dark brown spots on young leaves *(Plate 53)*, dark brown streaks on stems and leaf petioles, stunted growth, mottled fruit marked by light-green rings with raised centres, and orange or yellow bands that alternate with red bands in ripe fruits.

While TSWV is acquired by the larval stage of thrips, it is almost exclusively the adult that transmits the virus. Adults infect plants during feeding and remain infective for the rest of their lives (22–30 days). Adults do not transmit the virus to their young.

Management of this disease includes:

- roguing and proper disposal of infected plants
- keeping the interior and external surroundings of the greenhouse free of weeds and ornamentals
- monitoring for thrips using yellow or blue sticky cards, with lures added to increase their attractiveness to thrips
- inspecting plants for symptoms of feeding damage
- managing thrips populations
- screening vents and other openings to reduce movement of thrips into the greenhouse

Tomato Physiological Disorders

Blossom End Rot (BER)

This physiological disorder is commonly seen as a firm, dry, sunken and discoloured area (brown or black) at or near the blossom end of the fruit. It can range from less than 0.5 cm in diameter to an area affecting more than half the fruit *(Plate 54)*. It is caused by the lack of calcium movement to the distal end of the fruit, resulting in poor cell integrity and cell breakdown. This lack of calcium may be due to:

- lack of calcium supply in the feed or the growing media
- high EC, which prevents or decreases water uptake
- low moisture levels in the growing media and erratic watering
- excessive vegetative growth, which moves the majority of calcium to the leaves
- a dramatic change in fruit growth, resulting in higher calcium demand than the plant can supply to the affected tissue
- high VPD (or low RH), resulting in excessive transpiration and therefore less water movement to the fruit, resulting in less calcium being transported to the fruit
- a poor root system due to lack of aeration, thus decreasing water and calcium uptake

Blotchy Ripening

This disorder causes a type of uneven ripening, where certain areas on the tomato surface remain green or yellowish-green while other areas develop to their normal colour. Causes of blotchy ripening include low fertility levels, inadequate potassium, overcrowding, excessive fruit surface temperature and viral infection *(Plate 55).*

Blocky or Pointed Fruit

Some cultivars are more susceptible to this condition than others. A strong vegetative impulse under low light (particularly during winter and early spring), excess water and low EC will cause the fruit to become blocky and/or pointed. In the summer, pointed fruit is usually a response to stress caused by high temperatures *(Plate 56).*

Catface

This condition occurs when greenhouse temperatures are not high enough for normal fruit setting. Such fruits become misshapen and have irregular protuberances at the blossom end. Streaks and bands of dark greenish, scaly scar tissue often occur at the blossom end or at the sides of the tomato fruit.

Puffiness

Puffiness or hollow fruit may occur due to inadequate pollination, incomplete nutrition or low light levels. Frequently only one or two tomatoes on an individual truss may be affected. Fruits on subsequent clusters may not be affected if environmental conditions improve.

Nutrient Deficiencies and Toxicities

An imbalance of nutrients within tomato plants may cause various leaf symptoms that resemble disease. The most common of these is magnesium deficiency, which causes an interveinal light-green discoloration of the older leaves, especially during periods of heavy fruit load *(Plate 57).* Fortunately, greenhouse tomatoes are able to withstand a certain amount of magnesium deficiency without significant yield loss.

Low levels of calcium result in BER, as discussed earlier on page 80. Potassium deficiency causes chlorosis in the edges of the young upper leaves *(Plate 58)*, as well as blotchy fruit ripening. Iron deficiency may also occur, where leaves at the tops of the plants turn a mottled colour that ranges from light green to lemon yellow *(Plates 59, 60).* In severe cases, this causes a thinning of the upper stems and reduction of fruit set on the upper blossom clusters. A deficiency of manganese produces symptoms similar to iron deficiency. The most common symptom of manganese toxicity is a darkening of the main veins of the younger leaves, plus a browning and destruction of adjacent leaf tissue. A boron deficiency results in yellow discoloration of the distal leaf, with darkening of the midrib *(Plate 61).*

Russetting

Russetting, or shrink cracks, are minute hair-like cracks on the shoulders of tomato fruit. This disorder is present in some tomato cultivars and can be a problem since it reduces fruit quality. In mild cases, the cracks are visible under indirect light. In severe cases, they are readily visible. Russetting can be seen on immature green fruit, as well as on mature ripe fruit *(Plate 62).* In severe cases, the shoulder remains a grey-green colour, while the remainder of the tomato ripens normally *(Plate 63).*

This condition is thought to be due to fruit expanding faster than the skin can expand. Try to select a cultivar less prone to russetting but able to retain fruit size, plant habit, etc. Proper water management, plant balance, fertilizer schedule and greenhouse environment can also help minimize russetting.

2,4-D Injury

This herbicide was used for many years for weed control in field crops and lawns. Occasionally, greenhouse tomato crops are damaged by 2,4-D drift or contaminated sprayers. Plant symptoms can consist of fern-like foliage with leaf curl and plant stunting. Leaf growth becomes spindly, distorted and corkscrew-like; blossom set is reduced; and fruit that do set are misshapen.

Cucumber

Cucumber Diseases Caused by Fungi

Black Root Rot (Phomopsis sclerotioides)

This disease is quite common in cucumber crops grown in unsterilized or unpasteurized soils. While disease incidence has decreased with the increase in rockwool culture, it may occur where greenhouse hygiene is poor. This is especially true during the plant-raising stage in the propagation house, where contamination with infected soil may occur more readily.

Infected plants exhibit wilted leaves that recover at night. As the disease progresses, the recovery decreases, resulting in weaker heads, poor fruit set, permanent wilting and eventual death. Death usually occurs in conjunction with other pathogens. Examination of the roots with a hand lens reveals black rectangular discoloration patterns like a checkerboard along the infected root.

To decrease the risk of infection, pasteurize the growing media and follow proper hygiene procedures.

Damping-Off and Late Damping-Off (Pythium *and* Rhizoctonia)

Early damping-off and late damping-off symptoms are similar to those in tomatoes (page 75), since the same organisms are involved. *Pythium* and *Rhizoctonia* attack the roots of mature cucumber plants grown in rockwool culture, especially if conditions in the root zone are not properly managed. During the day, this results in wilting of the upper leaves that is more severe on sunny days. Although the leaves recover at night, the disease eventually leads to plant death. Affected plants also display brown-orange lesions at the base of the plant that may extend 10 cm along the stem. Roots are severely affected, becoming brown and easy to break.

Proper water management is the best strategy to minimize *Pythium* problems in mature plants, since overwatering and poor aeration are the two main causes of this disease in cucumber crops. Root zone temperatures that are too low or too high also promote *Pythium* infections. Avoid well water or creek water that may be contaminated by soil. If water from these sources must be used, disinfect it before use.

Grey Mould (Botrytis cinerea)

Botrytis cinerea attacks the leaves, fruit and upper stems of cucumber plants. It is a result of poor crop management and poor environmental control. The classic symptoms of grey mould are brown lesions with grey fungal growth that are visible at wound sites such as nodes *(Plate 64)*, fruit stems, broken leaves and, in severe cases, on the flower and tip of fruit.

Ensuring proper heat and ventilation is the best way to minimize the incidence of *Botrytis cinerea*. As well, use proper techniques when pruning stems and fruit stalks: cut cleanly, without leaving ragged edges.

Gummy Stem Blight (Didymella bryoniae)

Gummy stem blight is prevalent in most greenhouses but readily managed through proper cultural practices and environmental conditions. The disease attacks the stems, leaves, flowers and fruit. The symptoms are similar to those of *Botrytis* infection. However, a key difference is black pinpoint lesion spots (fruiting bodies of the fungus) that are visible on the stem when viewed with a hand lens. These lesions may exude a tan-coloured gummy exudate. In addition, the leaves show V-shaped yellowish-brown lesions. Usually, the fruit do not show any visible external injury; however, infected fruit tend to have a pointed blossom end. A brownish-yellow discoloration of the centre tissue is seen when infected fruit are cut lengthwise from the blossom end *(Plates 65, 66)*.

The gummy stem blight pathogen may survive for up to two years in a dormant stage in undecomposed plant debris. It requires a wound site to enter the plant and cause damage. Under the right conditions, 1 hour of leaf wetness is all that is required for infection to occur. Symptoms may take 3–10 days to display.

Management of this disease includes cutting out infected sites on the stem or removing infected plants; minimizing infection by adjusting the greenhouse environment to eliminate free water on the plants; and ensuring that any cuts at the nodes, fruit stalks, etc. are made cleanly to encourage early healing of the wounds. (See OMAFRA Factsheet *Gummy Stem Blight of Greenhouse Cucumber*, Order No. 09-051W.)

Penicillium Stem Rot (Penicillium oxalicum)

This disease damages plant tissue, causing extensive plant death within the crop. Disease symptoms are similar to those of grey mould and gummy stem blight, but a bluish-grey fungal growth is usually visible at the lesions. These lesions may occur anywhere along the stem, but are commonly seen at the base of the plant (10–15 cm above the block) and/or 1.0–1.5 m from the ground.

The disease usually attacks a pruned node, and the infected tissue may extend 10–15 cm above and below the infected node. Extensive internal tissue rot results in death of the plant above the infected point. Remove the infected tissue and up to 1–2 nodes of healthy tissue below the infected node to allow a new sucker to develop *(Plate 67)*.

Cultural practices, especially during the plant-raising stage, are critical in minimizing or eliminating Penicillium stem rot. These include growing transplants under high light, low RH or high VPD (0.6–0.8 kPa); feeding with a nutrient solution with a high EC; keeping the media a little on the dry side; adjusting the greenhouse environment to minimize or eliminate free water on the plants; and using a sharp knife that is frequently disinfected to minimize disease transfer when pruning.

Leaf Spots

Several air-borne fungi, including species of *Alternaria* and *Colletotrichum* (anthracnose) may cause round areas of dead tissue on cucumber leaves *(Plate 68)*. In severe cases, the spots may enlarge, grow together and destroy the entire leaf surface. It is easy to confuse with downy mildew fungus, which causes somewhat similar spots (especially in crops planted in August and September). However, downy mildew usually attacks the lower leaf surfaces and can be identified by the purplish fungal growth it produces.

All of these leaf spot diseases are most severe in areas of the greenhouse with poor air movement and high humidity. Fall crops are more prone to attack, especially when "sweating" occurs due to cold nights following warm, humid days.

Powdery Mildew (Podosphaera xanthii, formerly Sphaerotheca fuliginea)

This is one of the most common and serious diseases of greenhouse cucumber crops. All Ontario greenhouse cucumber growers experience incidences of powdery mildew during the cropping cycle. The first symptoms are small white powdery spots that appear on the upper surface of the leaf. These spots rapidly expand and spread to other leaves and can quickly cover the whole leaf, and even the stem and fruit in severe cases *(Plate 69)*.

Dry greenhouse conditions tend to promote the spread of the disease through sporulation, whereas free water on the leaf surface increases the rate of infection.

Use cultivars tolerant to powdery mildew to help manage this disease, because relying heavily on conventional fungicides for disease suppression can lead to resistance. Washing down the crop with water can help decrease the disease incidence but may increase the incidence of other fungal diseases such as gummy stem blight and Botrytis grey mould. This should be done only when the conditions allow the plant to dry rapidly.

Downy Mildew (Pseudoperonospora cubensis)

Downy mildew can occur in fall cucumber crops, particularly in greenhouses with inadequate ventilation. Symptoms are angular, light-green areas bordered by leaf veins *(Plate 70)*. As the disease progresses, the interveinal tissue turns yellow. A purplish fungal growth may be seen on the undersurface of the leaves.

Adjust the greenhouse environment to increase air movement and minimize free water on plant surfaces. Early application of fungicides is also necessary to limit disease spread. (See OMAFRA Factsheet *Downy Mildew in Greenhouse Cucumber,* Order No. 09-013W (available on the website only).)

Fusarium Root and Stem Rot of Cucumbers (Fusarium oxysporum f. sp. radicis-cucumerinum)

This disease causes the upper leaves of the plant to wilt and plant vigour to decline. The base of the stem is initially tan but later turns white and then light salmon. Lesions extend at least 20–30 cm upwards and may girdle the stem *(Plate 71)*. Roots of affected plants remain firm, in contrast to Pythium root rot where the roots become mushy.

This fungus may colonize rockwool blocks. Greenhouse sanitation is the key to minimizing infestations. Implement precautions similar to those for bacterial canker in tomato (page 77) to prevent disease spread. (See OMAFRA Factsheet *Fusarium Stem and Root Rot of Greenhouse Cucumber*, Order No. 01-081.)

Cucumber Diseases Caused by Bacteria

Bacterial Wilt (Erwinia tracheiphila)

The main symptom of bacterial wilt is a sudden collapse of the entire plant. In some cases, a single leaf may wilt first. There is no recovery. The striped and spotted cucumber beetles are the vectors of this disease. The bacteria live in the gut of these beetles and infect the plant when the beetles feed on it. Upon entering the plant, the bacteria reproduce rapidly in the plant's vascular tissues, producing gums that eventually block the vascular tissue, resulting in the collapse of the plant.

To control bacterial wilt:

- control cucumber beetles by chemically treating vegetation outside the greenhouse with products that will kill the cucumber beetles (see OMAFRA Publication 363, *Vegetable Production Recommendations*)
- isolate infected plants
- work in infected areas last
- disinfect all pruning and harvesting tools regularly
- screen the vents to prevent beetle entry

Cucumber Diseases Caused by Viruses

Cucumber Mosaic Virus (CMV)

Cucumber mosaic virus is usually associated with an aphid infestation, especially when fall crops are planted. The virus has a wide range of hosts, and aphids are one of the key agents of infection. Cucumber beetles can also spread this virus. Infected leaves and fruit display a light- and dark-green mottling, and the plant tends to lose vigour. Thin, spindly growth, weak flowers and abortion of newly formed fruit are common. The plant may eventually die *(Plates 72, 73)*. A sudden wilt of whole cucumber plants may occur and is often the result of a combined infection of CMV and *Pythium*.

To control infection:

- eliminate or minimize alternative hosts, including weeds, near the greenhouse
- screen greenhouse vents to prevent aphid invasion
- manage aphid populations (see Chapter 13 and OMAFRA Publication 835, *Crop Protection Guide for Greenhouse Vegetables*)

Cucumber Necrosis Virus

Although this virus is not common, it causes economic losses when infection occurs. Initial symptoms are pinhole spots in young leaves *(Plate 74)*. These spots enlarge and coalesce to produce large brown necrotic areas that resemble symptoms of a fungal disease *(Plate 75)*. Symptoms tend to be less visible during summer conditions. This virus is transmitted by a soil-inhabiting fungus, *Olpidium radicale*, that appears to infect only cucumbers and its relatives. Infection can spread by contaminated hands and tools that come into contact with wounds of uninfected plants. This virus is not known to be transmitted by seeds or aphids.

To manage this virus:

- disinfect nutrient solutions in recirculating systems
- remove and destroy infected plants
- disinfect hands and tools during cultural operations such as pruning, harvesting, etc.
- work in infected areas last
- steam-sterilize soil for soil-grown crops
- steam-sterilize soilless media or replace bags that held infected plants

Also refer to management procedures for Pepino mosaic virus in tomato, page 79.

Beet Pseudo-Yellows Virus

This virus is spread by the greenhouse whitefly. Symptoms are chlorotic yellowing between the veins of older leaves and yellow spotting between the veins on intermediate leaves *(Plate 76)*. Upper leaves may remain unaffected during the early stages. Diseased plants become less productive. To minimize infections, manage whiteflies (see Chapter 13 and OMAFRA

Publication 835, *Crop Protection Guide for Greenhouse Vegetables*) and remove weeds from the greenhouse and the area immediately outside it.

Watermelon Mosaic Virus

Symptoms of watermelon mosaic virus include distortion of the terminal growth, blister-like protrusions between the veins of older leaves and severe distortion and bump-like protrusions on the developing fruit. The sources of infection are not yet fully identified, but other plants (e.g., alfalfa and certain weed species) are suspected of harbouring the virus. It can be transmitted by aphids. Manage aphids and weeds. (See Chapter 13 in this publication, as well as OMAFRA Publication 835, *Crop Protection Guide for Greenhouse Vegetables* and OMAFRA Publication 75, *Guide to Weed Control.*)

Cucumber Physiological Disorders

Nutrient Deficiencies and Toxicities

A shortage of one or more of the major or minor elements necessary for plant growth may produce symptoms that resemble disease. One of the more common deficiencies in cucumber is magnesium deficiency, where certain cultivars develop lighter-green areas in the mid-section of the plant. This symptom is most pronounced on the older, fully developed leaves. Younger leaves near the tops of the plants and on suckers remain a normal green colour. Although the symptom may cause concern, especially to new growers, magnesium deficiency is seldom serious.

Calcium deficiency is a common problem in cucumber production, especially in the earlier, rapid-growth stage. The upper leaves become rounded and cupped downwards and may have light-brown or yellow edges. In severe cases, the growing point dies *(Plate 77)*. To minimize this problem, increase the supply of calcium in the fertility program during the early stages of the cropping cycle.

Occasionally, deficiencies of one or more of the minor elements may occur, especially when plants are grown in rockwool or other soilless media. If adequate amounts of minor elements are not included in the feeding solution, iron deficiency may occur *(Plates 78, 79)*. Manganese deficiency has also been noted on occasion.

Toxicity symptoms may also occur if too much of one or more of the major or minor elements are supplied. Severe toxicities usually result in leaf tissue burn.

Pesticide damage may mimic nutrient deficiencies and toxicities. If deficiencies or toxicities are suspected, send leaf samples for tissue analysis.

Pepper

Pepper Diseases Caused by Fungi

Pythium and Botrytis

The most common greenhouse diseases, Pythium and Botrytis rots, can affect pepper plants in a manner similar to tomatoes and cucumbers *(Plates 80, 81)*. See pages 75, 76 and 82 for details.

Fusarium Stem and Fruit Rot (Fusarium solani)

This disease can cause severe economic loss in greenhouse peppers if action is not taken. Early symptoms are lack of vigour and partial wilting of upper leaves on sunny days with slow or delayed recovery. Dark-brown, sunken lesions are visible on the stems at leaf nodes *(Plate 82)*. Fruit have a more flattened shoulder, pale or brown-coloured longitudinal striations and rot beneath the calyx *(Plate 83)*. (See OMAFRA Factsheet *Fusarium Stem and Fruit Rot of Greenhouse Pepper,* Order No. 01-083.)

Powdery Mildew (Leveillula taurica)

This disease is relatively new to Ontario and can be a serious problem. Early symptoms are mottled yellow and light-green areas on the upper leaf surface, followed by white, powdery fungal growth on the lower surface *(Plate 84)*. To control it, use measures similar to those for powdery mildew in tomato and cucumber (see pages 76 and 83).

Pepper Diseases Caused by Bacteria

Bacterial Stem Rot (Erwinia carotovora *subsp.* carotovora)

Wilting, the first sign of this disease, is caused by the breakdown of the inner stem tissues, creating a hollow stem. When the disease extends to the bark of the stem, the affected area appears brown and could be mistaken for Fusarium stem rot. Infection occurs through fresh wounds, especially those created by pruning and removing leaves. This disease does not occur on healthy leaves, but it can develop in older, dying leaves. Bacteria then enter stems from infected leaves through the vascular system. Bacterial stem rot is favoured by wet, humid conditions. This bacterium is commonly present in soil and also causes soft rot in many field vegetables *(Plates 85, 86)*. It has also been found in the gut of insect larvae and may be spread from infected tissue to healthy plants by adult insects.

This disease is best managed through key measures such as:

- implementing strict sanitation practices
- ensuring the plants are never wet by providing adequate venting and air circulation and controlling temperature and humidity
- avoiding lush or soft growth through optimum nutrition and watering regimes
- providing enough time for wounds to heal before sunset

Pepper Diseases Caused by Viruses

Pepper Mild Mottle Virus

Symptoms of this viral disease are usually mild on the leaves, consisting of mottling and a light- or dark-green mosaic. In contrast, symptoms on the fruits are usually more noticeable and could include reduced size, distorted shape with distinct raised and sunken areas, and colour streaking *(Plate 87)*.

Pepper mild mottle virus (PMMV) occurs worldwide, primarily in bell pepper and chili plants. This virus is closely related to tomato and tobacco mosaic virus and therefore has similar characteristics, but tomato is not a host. PMMV is seed-borne and very stable and can persist in the environment for at least several months on surfaces and in plant debris. It is also easily transmitted between plants by contaminated tools and workers' hands.

Using tolerant or resistant cultivars and sanitation measures is the best approach to managing this disease. When an infection is detected:

- carefully remove infected plants in garbage bags without contacting other plants
- restrict entry into infected rows to workers who use coveralls that are laundered daily and gloves that are changed at least daily
- work in infected rows last
- dip tools and gloved hands in a disinfectant while working in the crop

Also refer to management procedures for Pepino mosaic virus in tomato, page 79.

Tomato Spotted Wilt Virus and Impatiens Necrotic Spot Virus

Symptoms of these two diseases are variable. They include bronzing, dark-brown spots on young leaves *(Plate 88)*, dark-brown streaks on stems and leaf petioles, stunted growth, mottled fruit marked with light-green rings with raised centres, and orange or yellow bands alternating with red bands in ripe fruits. See notes on these diseases under *Tomato*, page 80.

Pepper Physiological Disorders

Elephant's Foot

The name aptly describes the symptoms. At the point of entry into the growing media, the base of the stem is flared, with the outer tissues peeling back, revealing a soft, dark-brown rot. The affected plants have reduced vigour and are more prone to diseases such as Botrytis and Fusarium stem rot. Fungus gnats are also attracted to this rotting tissue and may increase the incidence of *Pythium (Plate 35)*.

This disorder is often seen on plants that were raised under "soft" conditions in the starter house. To manage elephant's foot:

- avoid excessive fertilization, injury to the base of seedlings and overwatering
- provide proper air circulation
- control fungus gnats and other common pests that frequent the growing media (see Chapter 13 and OMAFRA Publication 835, *Crop Protection Guide for Greenhouse Vegetables*)

Blossom End Rot

This disorder is seen at the blossom end of the fruit, as well as on the sidewalls close to the blossom end *(Plate 89)*. A grey, water-soaked area is an early indication of damage. This area becomes sunken and assumes a tan-to-grey colour. Take corrective measures similar to those described for tomato, page 80.

Sunscald

This disorder is easily confused with blossom end rot since the symptoms are very similar. Sunscald symptoms are usually seen on the sidewall of the fruit as a dry, sunken, yellow-to-tan area surrounded by a distinct edge *(Plate 33)*. This disorder is a result of a poorly developed canopy that exposes young fruit to direct sunlight *(Plate 34)*. Increase leaf area to protect the fruit and use shade curtains (if available) or whitewash the exterior roof of the greenhouse to alleviate the problem.

Fruit Cracking

When the flesh of the fruit grows more quickly than the skin as a result of low temperatures and irregular watering, the fruit can split at the blossom end or vertically. Internal fruit growth due to low temperatures also results in fruit cracking *(Plates 90, 91)*.

Pointed Tip

Low-temperature regimes may also cause fruit to develop pointed ends, degrading its quality.

Silvering

Silvering occurs on pepper fruit when there is rapid fruit expansion. This may occur in winter as well as in summer. During the rapid expansion, the fruit skin is believed to separate from the fruit body, resulting in the silvering stripes *(Plate 92)*. This is a superficial problem and, except in severe cases, the fruit is marketable.

Nutrient Deficiencies and Toxicities

Because pepper plants are slow-growing, they take a long time to display deficiency symptoms of any nutrients that are missing in the fertilizer program. Once corrective measures are implemented, the plants take just as long to recover. For this reason, it is important to include all ingredients for the fertilizer program at all times at the appropriate levels (see Table 7–1, *Fertigation Schedule for Pepper*, page 56 and Table 7–2, *Weights of Fertilizer Required to Make Stock Nutrient Solutions*, page 57). *Plate 93* shows an example of manganese deficiency, while *Plate 94* shows an example of boron deficiency.

Lettuce

Lettuce Diseases Caused by Fungi

Botrytis Grey Mould and Downy Mildew

Botrytis grey mould and downy mildew are two of the most common diseases that affect lettuce. Managing the greenhouse environment is key to controlling these problems.

Pythium Root Rot (*Pythium spp.*)

Pythium can be a problem in Nutrient Film Technique (NFT) systems if the system is improperly designed; the flow rate, solution temperature or aeration is poorly managed; or the plants are overly stressed. The affected plants wilt and have brown, discoloured roots that fall apart when handled. The disease can spread rapidly through the production house. Disinfecting the nutrient solution using ultraviolet (UV) lamps will help prevent this spread.

Lettuce Physiological Disorders

Lettuce Tip Burn

This disorder is commonly seen in greenhouse lettuce production. The usual symptoms are the browning of the edges and tips of young lettuce leaves. In severe cases they coalesce to cause severe tip burn. Lettuce tip burn is caused by the lack of calcium translocation to the developing leaves. Increasing transpiration will increase calcium translocation to the leaf tip, decreasing visual symptoms.

Transpiration can be increased by:

- increasing ventilation
- increasing air circulation around the leaf surface using horizontal airflow fans or turbulators
- maintaining a slightly greater VPD or lower RH

Once leaf tip burn symptoms appear, they will not disappear and cannot be corrected by sprays, etc. Prevention is the key to eliminating lettuce tip burn.

Russet Spot

This is a problem common to lettuce during shipping and handling. Tan-to-brown spots appear at the veins of the lettuce and, in severe cases, can coalesce to greatly reduce the visual appeal of the product. Russet spot can be caused by storage temperatures that are too low, resulting in chilling injury, or by the presence of ethylene in the storage facility.

Eggplant

Eggplant Diseases Caused by Fungi

Pythium Root Rot (Pythium *spp.*)

Pythium root rot is one of the most common greenhouse diseases for eggplants, affecting them in a similar manner to tomatoes and peppers (see page 75). Generally, good greenhouse environment management and sanitation will minimize disease incidence. Proper water management is the best strategy to minimize *Pythium* problems in eggplant. Overwatering and poor aeration are the two main causes of Pythium rot.

Grey Mould (Botrytis cinerea)

This is another common disease affecting greenhouse-grown eggplants. Early symptoms are similar to *Botrytis* symptoms in tomatoes and peppers, but the primary site of infection is the flower. Greenhouse conditions with low VPD (high humidity) result in moisture condensation on the flower and fruit, allowing *Botrytis* infection to occur *(Plate 95).* Such infections prevent the petal ring from falling off, resulting in unmarketable fruit *(Plate 96). Botrytis* can be suppressed in eggplant by manipulating temperature and relative humidity, similar to *Botrytis* control in tomatoes (page 76).

Eggplant Physiological Disorders

Blossom End Rot

This disorder is not as readily visible in eggplants as it is in tomatoes and peppers because the grey discoloration is difficult to see on the darker-coloured fruit. The blossom end will display a grey, water-soaked area, which may become sunken and tan to grey in colour. Take corrective measures similar to those described for tomato (page 80).

Post-Harvest Damage

Because eggplant fruit skin is very tender, rough handling will leave marks on the skin, decreasing shelf life and consumer appeal. Minimize handling and treat harvested fruit with care.

12. Integrated Pest Management (IPM)

Integrated pest management (IPM) is a pest control philosophy that uses all available control strategies to keep populations of harmful insects and mites below an economic injury level. It does not advocate relying on pesticide spray programs to "eradicate" pests. Instead, it promotes the integration of cultural, physical, biological and chemical control strategies.

There are several reasons to reduce the unnecessary use of pesticides in greenhouses. First of all, too great a volume of pesticides or the misapplication of pesticides can lead to concerns over environmental pollution and ground water contamination.

Secondly, insects can develop resistance to any synthetic pest control product. Developing and registering new pesticides takes significant time and resources. It is essential to use available pesticides as minimally and as efficiently as possible to reduce the development of resistance in pests. The best approach to slowing down the development of resistance is using a combination of management strategies, reserving pesticides as a last resort.

Finally, the potential exposure of applicators and workers to pesticides and pesticide residues in greenhouses requires a critical evaluation of frequency of use and pesticide safety during application. See Chapter 10 and OMAFRA Publication 835, *Crop Protection Guide for Greenhouse Vegetables.*

Monitoring

Careful monitoring provides reliable information to guide an integrated pest management program. The most important components of monitoring are sticky traps and crop inspection.

Sticky Traps

The most common greenhouse monitoring technique is using sticky traps (cards or tape) to collect many species of flying insects. Yellow sticky traps are especially good for adult whiteflies, thrips, leafminers, fungus gnats and winged aphids, while blue sticky traps are especially attractive to western flower thrips. If a wide range of pests are present, use yellow traps.

When using sticky cards, it is important to provide adequate coverage. Use a distribution rate of one card every 100–200 m^2. Choose the higher or lower end of this range based on the size of the operation being monitored, the pest incidence and the time of year. Change traps frequently enough that it is easy to count and record the number of insects caught every week.

Crop Inspection

Another important but often overlooked monitoring technique is crop inspection. It is essential for monitoring the presence of mites, wingless aphids, the immature stages of whitefly and leafminer damage on the leaf. Adopt a regular sampling pattern that provides good coverage of the whole greenhouse, including entry points and areas of concern. Again, weekly records are necessary.

Detecting sedentary pests (such as aphids or mites) early makes control easier and may permit management of a problem with only a spot spray or increased spot application of biocontrol agents.

For successful IPM, record the following as part of a regular pest-monitoring program:

- the date
- the crop species and cultivar
- the pests identified
- their location in the greenhouse
- the number of insects trapped
- the stage of development (e.g., adults, pupae)
- the control action taken (pesticide or biocontrols used, rate, area treated, time taken, etc.)

Cultural Controls

Sanitation

For details, see Chapter 10, page 70.

Environmental Manipulation

Environmental factors such as light, temperature, humidity, water and nutrients can affect not only the plants but also the pests that afflict them. This makes the use of environmental controls to manage pests a complex process. Each case is different and needs to be assessed carefully.

For example, humidity can play an important role in pest development. Spider mites prefer hot, dry conditions. Increasing the humidity by using overhead misting can help slow the development of this pest.

During the winter, thrips are not particularly mobile. This is probably due to low light levels rather than to low temperatures, and it can have implications for monitoring programs. At these times of the year, yellow sticky cards may not catch thrips, even when they are present and actively feeding in the crop.

For more information on environmental manipulation, see Chapter 10, page 70.

Physical Control

Screening

Putting screens over vents can greatly reduce the influx of insect pests from outside. In warmer climates where pests occur outside all year, screening is an established part of IPM programs. While not as common in temperate areas, screening is becoming more accepted and its value more apparent.

Screening removes an important variable from a grower's pest management program: the movement of pests into the greenhouse from outside. This includes common greenhouse pests such as thrips, aphids and whiteflies but also some less common pests such as tarnished plant bug and European corn borer. All of these can create major pest problems when pesticide use is reduced (e.g., in biological control programs).

The benefits of using insect screening have been demonstrated in Israel and California. Similarly, Ontario growers who installed screens report reduced numbers of pests, lower pesticide use and improved effectiveness of pest control measures (especially biological control measures).

The most important considerations in screening a greenhouse are the type of pests being targeted for exclusion and how the screens will affect the venting capacity of the greenhouse.

The size of the pest determines the mesh size of the screen needed. The large mesh sizes normally found in household screens are too big to exclude most major greenhouse pests. However, they can be useful in keeping out occasional larger pests such as tarnished plant bug and lepidopteran (moth) pests. For smaller insects such as thrips, the mesh must be very fine to achieve total exclusion. When there are multiple pests of concern, choose a mesh size that will exclude the smallest of these pests.

Reduction of airflow is a major concern with screening. Even larger mesh sizes can significantly reduce air movement.

Reduced airflow can lead to overheating of the greenhouse. In the case of fan-ventilated greenhouses, it also puts stress on the fans, since they have to work harder to pull the same amount of air through the partially blocked vent. Address reduced ventilation by increasing the surface area of the screened openings. In many situations, this can be achieved by building a screened framework around the vent opening. Note that forced ventilation/wall vents are much easier and less expensive to screen than top vents. The goal is to ensure that the final surface area of the screens provides sufficient air exchange to allow adequate cooling of the greenhouse.

Several factors determine how much extra vent surface area must be added to compensate for the screen:

- screen mesh size
- fan capacity
- static pressure drop (the difference in air pressure between the inside and the outside of the greenhouse when the fans are running)

Although software programs exist to help with these calculations, they can be complicated and are generally best left to the screening manufacturers.

The small pore size means that screens can easily become blocked with dust and other deposits, especially in the summer. This reduces airflow through the screens and may contribute to excessively high temperatures in the greenhouse. It is important to:

- clean screens regularly
- make sure easy access for cleaning is incorporated in their design

Wash screens from the inside with a high-pressure hose. Do not do this when the fans are operating. The water will block the pore openings and completely stop airflow, leading to overheating of the greenhouse.

The effectiveness of the screens depends on their ability to exclude flying insects. Repair tears or holes as soon as possible. Small tears can be repaired by gluing a piece of screening over the hole.

The cost of screening depends on several factors:

- the final screening design
- the increase in surface area needed to maintain adequate ventilation
- the cost of the screening material
- whether the vents to be screened are roof vents or side vents
- the frequency of screen replacement
- labour costs for cleaning

For further information, see OMAFRA Factsheet *Screening of Greenhouses for Insect Exclusion,* Order No. 00-021.

Yellow Sticky Tape

Yellow sticky tape can provide useful additional control of flying insect pests. It works on the same principle as the sticky cards used for monitoring. Place the tape along plant rows or hang it vertically within the crop.

Light Traps

Light traps also provide an easy-to-use, non-chemical alternative for reducing and suppressing moth pests such as tomato pinworm adults and adult cabbage loopers. Light traps use a combination of black-light lamps for attracting insects and a low-voltage electrocutor that surrounds the lamps. These lamps emit long-wave ultraviolet (UV) radiation around 365 nanometres (nm). They also emit some visible light in the range of 430–540 nm. Ultraviolet light is the most effective part of the light spectrum for attracting night-flying insects, hence its use in attracting nocturnal moths.

Consider the following factors when using light traps:

- **Size:** The bigger the trap, the greater its power to attract moths. Most traps can attract moths within a diameter of 40–50 m. Larger ones are more expensive.
- **Location:** Ideally, place traps in locations best suited to their attracting range. However, because convenience tends to dictate their location, most growers usually place them along walkways. In either case:
  - Place a large sticky board or a receptacle containing soapy water below the trap to catch the insects
  - Place the traps high enough so that the plants don't block the light emitted from the trap or hinder access by smaller moths
  - Place traps just above the plant canopy
- **Time of year:** Light traps are best used during the cooler months of the year when outdoor temperatures are 10°C or less. This eliminates the problem of attracting more flying pests into the greenhouse. However, during the warmer months, place the traps at a safe distance outside the greenhouse to attract adults away from the greenhouse.
- **Maintenance:** To maintain efficiency, inspect and clean the light traps regularly.

Bumblebees

Light traps attract and kill bumblebees. To avoid or minimize the trapping of bees, use a timer so the lights are turned on at dusk and off at sunrise. Some biological control agents may also be attracted to the lights. However, lower night temperatures should reduce activity of most of these agents, reducing the chances of trapping. Many moth pests, on the other hand, tend to be more active at night.

Using light traps during the cooler months of the year is a good non-chemical strategy for managing moth pests.

Biological Control

Biological control (biocontrol) is the use of living organisms such as beneficial insects, mites, fungi and bacteria to control pests such as harmful insects and mites. Biological control involves more than the release of parasites or predators. A successful program requires planning at least several months in advance. Consider the following before using biological control:

- Develop a list of resources to help with the program (this may include producers/suppliers of biocontrol agents, other growers, extension specialists, researchers and consultants). Attend courses, seminars and workshops; read magazines and newsletters; and use the Internet to find out as much as possible about biocontrol. Determine what pests should be targeted for control and which are the most appropriate natural enemies to use. (See Table 12–1, *Biocontrol Agents for Major Greenhouse Pests.*)
- If possible, start in a small isolated greenhouse. This allows beginners to focus on one small area and to become more comfortable with using biological control. Subsequently expand the program to include the entire greenhouse operation, thus minimizing chances of economic failure.
- If possible, screen the area to be used (see *Screening,* page 90). Movement of outside pests into the greenhouse varies from year to year but can swamp a biocontrol program and make it difficult for the natural enemies to maintain control.
- Ensure all employees are trained to recognize the pests, biocontrol agents and early symptoms of pest damage.
- Many registered pesticides can have residual impacts that last 2–3 months or longer. Check the pesticide spray records of the previous several months. If such pesticides have been used, wait the appropriate length of time before starting. Use products with less residual impact to control pests during this period. Residual effects of several pesticides are listed in Table 12–2, *Reported Effects of Registered Insecticides/Miticides on Biological Control Agents,* page 94 and Table 12–3, *Reported Effects of Registered Fungicides on Biological Control Agents,* page 94 or are available from biocontrol suppliers.

Table 12–1. Biocontrol Agents for Major Greenhouse Pests

Pests	**Biocontrol Agent**
Aphids: various species Green peach aphid *(Myzus persicae)* Melon aphid *(Aphis gossypii)*	*Aphidius* spp. (parasitic wasps)* *Aphidoletes aphidimyza* (predatory midge)** Lacewings** Ladybeetles *(Hippodamia* sp.*)***
Caterpillars (cabbage loopers, European corn borers)	*Bacillus thuringiensis* (bacterium sold as DiPel, Foray, etc.) *Cotesia marginiventris* (parasitic wasp)* *Trichogramma* spp. (parasitic wasps)*
Fungus gnat *(Bradysia* and *Corynoptera* spp.*)*	*Atheta coriaria* (predatory beetle)** *Bacillus thuringiensis* (bacterium sold as Vectobac) *Hypoaspis* spp. (predatory mites)** *Steinernema* sp. (nematode)**
Leafminer *(Liriomyza* spp.*)*	*Dacnusa* sp. (parasitic wasp) * *Diglyphus* sp. (parasitic wasp)*
Spider mite *(Tetranychus urticae)*	*Amblyseius californicus* (predatory mite)** *Feltiella acarisuga* (predatory midge)** *Phytoseiulus persimilis* (predatory mite)** *Stethorus punctillum* (predatory beetle)**
Whitefly *(Trialeurodes vaporariorum* or *Bemisia argentifolii)*	*Delphastus pusillus* (predatory beetle)** *Dicyphus hesperus* (predatory bug)** *Encarsia formosa* (parasitic wasp)* *Eretmocerus eremicus* (parasitic wasp)*
Western flower thrips *(Frankliniella occidentalis)*	*Amblyseius* spp. (predatory mites)** *Atheta coriaria* (predatory beetle)** *Hypoaspis* sp. (predatory mite)** *Orius* spp. (predatory bug)** *Steinernema feltiae* (nematode)**

* *Parasitoids: These usually require only one host for completion of development, often killing it by living on or in its body.*
** *Predators: These feed on their prey (pest) by catching them but otherwise live independently of them. They must consume more than one individual to reach maturity.*

Caution is required when using pesticides along with biocontrols since most pesticides are harmful to beneficial insects. Using even one application of harmful pesticide can prevent any further use of biocontrol agents for an extended period of time. See Table 12–2 and Table 12–3.

Table 12–2. Reported Effects of Registered Insecticides/Miticides on Biological Control Agents[a,b,c]

Insecticides	***Encarsia formosa* + *Aphidius***	***Phytoseiulus persimilis***	***Amblyseius cucumeris* + *Hypoaspis***	***Aphidoletes aphidimyza***	***Orius* spp.**
Ambush/Pounce	H (56–84)	H (14–84)	H (56–84)	H (56–84)	H (56–84)
Avid	H (21)	H (14)	H (14)	H (21)	H (21)
Basudin	H (28–42)	H (7)	H (7–21)	H (42–56)	H (30)
Bioprotec	S (0)	S (0)	S (0)	S (0)	S (0)
Citation	S	S	S	H	I (7)
Confirm	S	I	S	—	I
Diazinon	H (28–42)	H (7)	H (7–21)	H (42–56)	H (30)
Dibrom (Fumigant)	H (7)	H (3–7)	H (3)	H (7)	H (3)
DiPel	S (0)	S (0)	S (0)	S (0)	S (0)
Distance	H (35)	S	S	I (0–7)	S
Dyno-Mite	H (>28)	H (7)	H (28–36)	H (>28)	H (28–35)
Endeavor	I (0)	S	S	I	S
Floramite	—	I (7)	—	—	S
Foray	S (0)	S (0)	S (0)	S (0)	S (0)
Insecticidal Soap	H (0)	H (0)	H (0)	H (0)	H (0)
Intercept	S	S (0)	S (0)	S	H (28–42)
Malathion	H (56–84)	H (7–14)	H (56–84)	H (14–70)	H
Nicotine (Fumigant)	I (3)	H	H (1–7)	H (1–7)	I
Thiodan	H (56–84)	H (4–14)	H (42–70)	H (56–84)	H
Vectobac	S	S	S	S	S
Vendex	S	S	S	S	S

[a] *S = Safe; H = Harmful; I = Intermediate; numbers in parentheses refer to residual toxicity to biological agent, in days, where reliable data exists. "—" indicates no data is available.*

[b] *This table serves only as a guide to possible effects of pesticides. Variations in toxicity may occur under varying conditions.*

[c] *This table was compiled from information produced by Applied Bionomics Ltd. (www.appliedbio-nomics.com/technical-manual/180-chemical-effect.pdf), Biobest Biological Systems (www.biobest.be/neveneffecten/3/3/) and Koppert Biological Systems (http://side-effects.koppert.nl). Where differences existed in the available information, it provides either a range of residual toxicities or the more conservative figure. Please refer to these websites for more comprehensive information.*

Table 12–3. Reported Effects of Registered Fungicides on Biological Control Agents[a,b,c]

Fungicides	***Encarsia formosa* + *Aphidius***	***Phytoseiulus persimilis***	***Amblyseius cucumeris* + *Hypoaspis***	***Aphidoletes aphidimyza***	***Orius* spp.**
Benlate	S (0)	H (14–21)	H (14–21)	S (0)	S (0)
Botran	S	S	S	S	—
Captan	S (0)	S (0)	S (0)	S (0)	S (0)
Decree	—	I	—	—	I
Maestro	S (0)	S (0)	S (0)	S (0)	S (0)
Manzate	S (0)	S (0)	S	H	S (0)

Fungicides	***Encarsia formosa* + *Aphidius***	***Phytoseiulus persimilis***	***Amblyseius cucumeris* + *Hypoaspis***	***Aphidoletes aphidimyza***	***Orius* spp.**
Mycostop	S	S	S	S	S
Nova	S	S (0)	—	—	S (0)
Previcur	S (0)	S (0)	S	—	I
Pristine	S	S	S	S	S
Ridomil Gold	S	H	I	—	—
Rootshield	S	S	S	S	S
Rovral	S (0)	S (0)	S (0)	S (0)	S (0)
Sulphur	H (>28)	S (0)	I	I	S

[a] *S = Safe; H = Harmful; I = Intermediate; numbers in parentheses refer to residual toxicity to biological agent, in days, where reliable data exists. "—" indicates no data is available.*

[b] *This table serves only as a guide to possible effects of pesticides. Variations in toxicity may occur under different conditions.*

[c] *This table was compiled from information produced by Applied Bionomics Ltd. (www.appliedbio-nomics.com/technical-manual/180-chemical-effect.pdf), Biobest Biological Systems (www.biobest.be/neveneffecten/3/3/) and Koppert Biological Systems (http://side-effects.koppert.nl). Where differences existed in the available information, it provides either a range of residual toxicities or the more conservative figure. Please refer to these websites for more comprehensive information.*

- Check commercial biocontrol agents to evaluate their activity and the approximate numbers required. The quality of natural enemies produced by the major suppliers is usually excellent, but problems can occasionally arise in shipping. The supplier needs to know about any problems in quality in order to identify and correct them.
- Follow all instructions for storing and releasing the natural enemies. Many can be stored only for a short period of time under fairly specific conditions.
- Monitor populations of pests and natural enemies and the progress of the biocontrol program by regularly checking for the following:
  - The presence of winged biocontrol agents on sticky cards, especially parasitic wasps. Be aware that some (e.g., *Eretmocerus*) are highly attracted to yellow, so too many sticky cards may be detrimental to the program.
  - The presence of parasitized insects. For example, black scales reveal that *Encarsia* has parasitized whiteflies, while mummified aphids indicate that they have been parasitized by *Aphidius* parasitic wasps.
  - The presence of non-winged natural enemies (e.g., predatory mites and immature ladybeetles that do not fly) requires visual inspection the crop. Pay particular attention to areas of highest pest numbers.
  - Pest population trends. Monitor pests either on cards or the crop to determine if populations are increasing or decreasing.
- If necessary, use compatible pesticides. Identify such pesticides before starting a program so they can be readily used when needed. See Tables 12–1 and 12–2, as well as OMAFRA Publication 835, *Crop Protection Guide for Greenhouse Vegetables.*
- Remember that successful biocontrol programs require patience and experience.

Commercially produced biocontrol agents are available for all major greenhouse insect and mite pests. For more details about implementing biological control or about supplies of parasites/predators, consult OMAFRA's greenhouse vegetable pest management specialist or biological control suppliers.

Chemical Control

Resistance

Resistance is the evolutionary adaptation of a population to survive a pesticide dose that is lethal to most of its individuals. It is an inherited trait, which is passed on to future generations. While an individual cannot develop resistance during its lifetime, a few individuals in a population (too few to be measured or noticeable) are usually born with resistance. The frequency of resistance in a population increases when pesticide exposure kills susceptible individuals while allowing successively greater numbers of resistant individuals to survive. Because of the immense genetic diversity of arthropod pests, their short life cycles, their great reproductive ability and the relatively closed nature of greenhouse production, greenhouse insect and mite pests have great potential to develop resistance. Relying on chemical control inevitably leads to the development of resistant populations.

Resistance can develop to any pesticide used incorrectly or too often. Although new products may be developed that can replace pesticides that are no longer effective, do not depend on the latest advance in pesticide chemistry to solve pest problems. Pesticide resistance is a long-term problem, and new products will provide only short-term gains if growers use them incorrectly.

Resistance management programs aim to reduce the pressure that pesticides apply to pest populations. The best approach is to minimize the use of pesticides by regarding them strictly as a last-resort measure and using biological control as the major strategy, integrating chemical controls only when necessary. Follow good sanitation practices to reduce pest pressure. Where applicable, incorporate physical controls such as insect barriers and traps.

Note that using one class of pesticides (e.g., organophosphates, synthetic pyrethoids, carbamates) for a prolonged period speeds up the development of resistance. To slow the rate of resistance development, it is important to rotate pesticide classes every few weeks or for a period equal to the generation time of the pest being controlled. For a chemical classification of products, see OMAFRA Publication 835, *Crop Protection Guide for Greenhouse Vegetables.*

Use pesticides responsibly so that new products do not lose their effectiveness prematurely.

Pesticide Application

In addition to the level of pesticide resistance within a pest population, several other factors determine the effectiveness of a particular pesticide application. To maximize effectiveness:

- Ensure the pesticide application rates are accurately calculated and measured.
- Ensure proper coverage is achieved. Simple changes, such as walking more slowly through the crop or walking every aisle while spraying instead of every other one, significantly improve performance.
- Maintain spray equipment in good condition. Replace spray nozzles regularly. Older nozzles become worn, which can alter the spray pattern and droplet size.
- Consider different application technologies. High-volume, low-volume and electrostatic-spray application all have their place in the greenhouse for appropriate purposes.
- Time and target sprays for greatest impact. A scouting program can provide the information required to decide when, where and why a pesticide application is needed.
- Adjust water pH to 5.5–6.0. At a pH greater than 7, the pesticide may degrade rapidly.
- Keep in mind the usage history of a particular product within the greenhouse.

Pesticide Compatibility

Before mixing pesticides, read the product labels carefully for compatibility statements or contact the supplier. Avoid mixing products with different electrical conductivity (EC) formulations. Never mix herbicides with fungicides or insecticides; apply herbicides with spray equipment reserved for herbicide use only.

13. Insect, Mite and Other Pests

Thrips

Description and Life History

Thrips are tiny, slender, agile insects about 1.5–2 mm in length when fully developed. Adults vary in colour from dark brown or black through to yellow or straw brown. The immature insects usually have white or yellow bodies with red eyes. Several thrips species are found in the greenhouse, including eastern flower thrips, onion thrips and western flower thrips (WFT) *(Plate 97).*

All thrips have a similar life cycle. The adult female lays tiny, white eggs in developing leaves. The eggs hatch in 5–7 days, and the white larvae emerge to feed on the leaves and petals. They pass through 2 larval stages, a prepupal stage and then a pupal stage (on the soil or plant) before becoming adults. Adults can live up to 7 weeks. A new generation may occur every 20–35 days, depending on the temperature.

Damage

Piercing/sucking mouthparts cause white streaked areas on leaves and fruits or translucent spots on flower petals. Tiny, black fecal deposits on leaf surfaces are signs that thrips have been feeding on the plant. Adult females can also damage the quality of fruit (e.g., tomatoes) by laying eggs in them. Small whitish "ghost-spots" appear where eggs are laid, which cause uneven fruit ripening *(Plate 98).*

Thrips can carry impatiens necrotic spot virus/tomato spotted wilt virus (INSV/TSWV), which can devastate many common greenhouse crops *(Plate 99).* Proper diagnosis is essential, as these viruses have a wide host range and produce a wide variety of symptoms. Control of INSV/TSWV is difficult, involving thrips population management, removal of infected plants and good weed control. Note that thrips rapidly develop pesticide resistance. Use of indicator plants such as petunia or fava bean can be a useful means for early detection of INSV/TSWV.

Control Strategies

Employ a regular monitoring program using yellow or blue sticky cards (both these colours are very attractive to WFT) and regular crop inspection. Commercially available lures attached to sticky cards could increase their attractiveness to WFT.

All mobile stages of the thrips can be detected by tapping buds or flowers over a sheet of white paper.

Biological Control

Several biological control agents are available for thrips control:

- predatory mites including *Amblyseius cucumeris, Amblyseius swirskii, Amblyseius degenerans* and *Hypoaspis*
- the predatory bug *Orius insidiosus*
- the predatory rove beetle *Atheta coriaria*

The best control is obtained by using two or more of these in combination. Introduce biocontrols when pest levels are low, using a sufficient quantity to achieve success.

Amblyseius cucumeris

This buff-coloured predator feeds mainly on the first nymphal stage of thrips. *Amblyseius cucumeris* is usually shipped to growers in a mixture that includes bran and bran mites. The bran provides food for the bran mites, which are themselves food for the predatory mites. The bran/mite mixture is available in two forms: small sachets that serve as small rearing units from which predatory mites emerge over several weeks or in containers from which the mixture is sprinkled directly onto the crop.

Always examine the bran mixture before using it. The bran should not be mouldy or smell of ammonia, and live predatory mites and bran mites should be visible. Healthy predatory mites move rapidly, whereas bran mites move more slowly. If sachets are used, hang them in sheltered positions to minimize dehydration of the bag contents. Rates of application of this predator vary with the crop and the level of thrips infestation.

Contact the biocontrol supplier, consultant or OMAFRA Greenhouse Vegetable IPM Specialist for suggested rates.

Amblyseius swirskii

This predator closely resembles *A. cucumeris,* and it is very difficult to differentiate one from the other. This predatory mite has contributed to increased success in biological control programs for western flower thrips. Like *A. cucumeris,* it feeds mainly on the first nymphal stage of thrips. However, unlike *A. cucumeris,* it also preys on the eggs and first larval stage of whiteflies. *A. swirskii* does not diapause. It tolerates high temperatures but not low relative humidities. It can also develop on the pollen of sweet pepper and eggplant and is particularly useful on these crops, as well as on cucumbers. It is not reported to establish on tomatoes.

Amblyseius degenerans

This predator differs from *A. cucumeris* in appearance and in being able to tolerate less humid conditions. It is dark and very agile and reproduces very well on pollen. *Amblyseius degenerans* can be reared on castor bean plants, which may be used as release points for the predator within the greenhouse. It performs best in situations where it has a pollen source to encourage establishment (e.g., greenhouse peppers).

Hypoaspis

This soil-dwelling mite provides additional thrips control by feeding on pupae in the crop media. For more details, see *Fungus Gnats/Shoreflies,* page 108.

Orius insidiosus

Orius insidiosus, the minute pirate bug, is a winged predator that consumes all mobile stages of thrips. Adults are black with white and cream markings on the wings. The youngest nymphs are yellow, while the oldest ones are a dark, mahogany brown. *Orius* also feeds on pollen, spider mites, aphids, whiteflies, moth eggs and young caterpillars. However, its preferred food source is thrips. Pirate bugs are sensitive to day length and should not be released in greenhouses before mid-March unless at least 13 hours of light are provided.

Atheta coriaria (Rove Beetle)

This soil-dwelling beetle was originally developed for control of fungus gnats and shoreflies but also feeds on thrips pupae in the soil. For more information, see *Fungus Gnats/Shoreflies,* page 108.

Chemical Control

Chemical control of WFT can be difficult because they tolerate most pesticides and feed deep within the flower or on developing leaves, making them a difficult target for insecticides. Thorough coverage is essential. When using pesticides for thrips control:

- Rotate chemical classes (if more than one class is available), using a single chemical class only for the duration of the thrips' life cycle. This generally means using a different class every 2–3 weeks, depending on the time of year. Generation times are longer at cooler temperatures.
- Apply pesticides in the early morning and late afternoon, when flight activity of thrips peaks. This increases exposure of the thrips to the pesticides.

Whiteflies

Description and Life History

Adult whiteflies are small, winged, white insects about 1.5–2 mm long. They lay eggs on the underside of the youngest leaves. The eggs are too small to be seen clearly without a microscope. A female whitefly may lay up to 300 eggs during her lifetime and can live up to 2 months. The nymphs or crawlers hatch in 5–10 days, are flat and scale-like and crawl around for a short while before becoming immobile.

Adults emerge after 3 nymphal stages and 1 pupal stage. Old pupal skins and adults may be found on the underside of lower leaves, which may have symptoms of wilt. On average, the whitefly completes its life cycle in 35 days at 18°C and in 18 days at 30°C. Whiteflies have no special overwintering stage and can usually survive as long as some kind of plant life is available *(Plate 100).*

Species of Whiteflies

Two whiteflies concern growers in Ontario: the greenhouse whitefly (GWF) and the silverleaf whitefly (SLWF). GWF and SLWF adults are subtly different in appearance:

- The SLWF is slightly smaller than the GWF, and its body is more yellow.
- At rest, the SLWF holds its wings in a tent-like position above its body, while the GWF holds them flatter and more parallel to the surface on which it is resting.
- The SLWF flies in a more direct manner, while the GWF assumes a more haphazard flight pattern.
- The life cycle of the SLWF takes 1 to 2 days longer to complete.
- The SLWF is less adapted to cold conditions.

The major diagnostic differences between GWF and SLWF appear in the pupal stages. The GWF pupa is raised off the leaf surface and is surrounded by a fringe of hairs, while the SLWF pupa sits flat on the leaf and does not have a fringe. These features are best seen with a microscope.

Damage

- Piercing/sucking mouthparts allow whiteflies to remove sap from the plant, reducing plant vigour.
- Whiteflies excrete large amounts of a sugary substance called honeydew. Honeydew promotes the growth of a black, sooty mould on leaf and fruit surfaces, reducing photosynthesis and fruit quality respectively. The sooty mould itself does not damage the plants.
- Whiteflies can transmit viruses. For example, the SLWF is reported to transmit more than 60 viruses, and the GWF has been associated with the spread of beet pseudo-yellows virus in cucumbers.

Control Strategies

To keep whiteflies under control:

- Implement a routine monitoring program using yellow sticky cards and plant inspections.
- Use host plants such as eggplant and fuchsia that are more attractive to whiteflies than the main crop as an early detection tool or trap plant.
- Identify the whitefly species present on the crop.
- React promptly to the presence of whitefly adults either on cards or on terminal leaves.
- Maintain good weed control both inside and outside the greenhouse.

Biological Control

Two parasitic wasps are commercially available for whitefly control: *Encarsia formosa* and *Eretmocerus eremicus. Encarsia formosa* is more effective against GWF but provides some control against SLWF. *Eretmocerus* is more effective against SLWF but also provides good control of GWF. Two predators are also available commercially: a small, black beetle, *Delphastus pusillus*, and a predatory bug, *Dicyphus hesperus*.

Good sanitation and weed control are essential for successful biological control of whitefly. Start biological controls at the first sign of whitefly, since these controls are less effective once pest numbers get too high.

Encarsia formosa

The adult wasps are about 0.6 mm long and suppress whitefly populations mainly by laying eggs into the immature stages or scales. Adult *Encarsia* can live for a few days to a month, depending on the temperature. Females lay 50–350 eggs in their lifetime. GWF scales turn black 10–14 days after being parasitized, and the adult wasp emerges an average of 2 weeks later, cutting an opening in the top portion of the scale. Parasitized SLWF turn tan-brown and are less easily noticed. For biological control of SLWF, consider higher introduction rates relative to GHWF because SLWF is more difficult to control.

To use *Encarsia* successfully:

- Avoid pesticides with long residual effects for at least 3 months before the initial release.
- Monitor the crop for whitefly presence at all production stages and follow population level trends to determine the most effective timing and location of parasitoid releases.
- Introduce *Encarsia* at the first sign of whitefly or preventively before whiteflies are detected. If whiteflies are present before *Encarsia* is released, knock back populations with a low-residual pesticide.

- If *Encarsia* is used between December and February, adjust light and temperature conditions to suit the parasitoid.
- Distribute *Encarsia* in shaded parts of the plant where the parasitoids are protected from direct sunlight.
- Distribute cards relatively evenly, but place more in areas where whiteflies have been observed. To achieve better distribution, purchase cards with fewer parasitized scales per card.
- Do not remove leaves with immature parasitized scales during deleafing or pruning operations in vegetable crops such as tomato. Removing these leaves slows the buildup of *Encarsia* numbers and the parasitism rate.
- Continue introducing *Encarsia* until at least about 80% of the scales on older leaves are black (or tan, in the case of SLWF). During warmer months when whiteflies migrate into the greenhouses, maintain or increase introductions.

Eretmocerus eremicus

Adults are about 0.6 mm long and yellow. They lay eggs under the whitefly larvae, particularly larvae in the second or third stage. This wasp has a sex ratio of 1:1 (male:female). Introduction rates refer to the number of females introduced (unlike *Encarsia*, where all individuals are female). Like *Encarsia*, *Eretmocerus* kills whiteflies through parasitism and host feeding. In the case of both GWF and SLWF, the parasitized whitefly pupa is yellowish-brown.

Delphastus pusillus

Delphastus is a predatory beetle. Both adult and larval *Delphastus* feed on whiteflies, particularly on the eggs and nymphs. *Delphastus* are reported to avoid parasitized scales, preferring to feed principally on non-parasitized scales. This behaviour makes *Delphastus* compatible with *Encarsia*. Use these beetles to supplement the activity of *Encarsia* in reducing whitefly populations. Adult *Delphastus* live for 6–9 weeks. They are reported to require at least 10 whitefly eggs/day to reproduce. These beetles are reported to work well on cucumber but not tomato crops.

Dicyphus hesperus

Dicyphus is a predatory bug with piercing/sucking mouthparts. These bugs are general feeders, but they appear to have a preference for whiteflies, feeding particularly on the eggs and larval stages. To a lesser extent, they will feed on aphids, spider mites, thrips, leafminer larvae and moth eggs. In the absence of prey, a high population of *Delphastus* may cause damage to tomato fruits. For management of whiteflies, it is best to use *Delphastus* in conjunction with the parasitic wasps *Encarsia formosa* and *Eretmocerus eremicus.*

Physical Control

Sticky traps

Use yellow sticky traps in various forms to trap large numbers of adult whiteflies. Large, yellow sticky boards or 30-cm yellow sticky tapes can be placed in "hot spots" at a rate of about one per plant. Alternatively, hang yellow sticky tape between posts along plant rows. These tapes will also trap fungus gnats, shoreflies, *Aphidius* spp., *Eretmocerus* and *Encarsia*, especially when whitefly population levels are low. Be careful in using large quantities of sticky tape in conjunction with parasitoids, especially *Eretmocerus*, which is highly attracted to the colour yellow.

Vacuuming

Hand vacuuming of adults in "hot spots" is a very effective way to rapidly remove adult whiteflies.

Insect barriers

Installing fine screens over vents and doorways will significantly reduce the movement of outdoor populations into greenhouses. Where whiteflies move in from adjacent field crops (e.g., field tomatoes) in large numbers at the end of the outdoor season, consider screening as a first line of defence.

Chemical Control

Whiteflies have developed resistance to many pesticides. If chemical control is required, be sure to use it judiciously to extend the effective life of pesticides that currently work against whiteflies.

Rational and judicious pesticide use requires a regular monitoring program, using action thresholds, rotating chemical classes and incorporating the use of all available non-chemical control strategies.

When using a systemic insecticide, ensure that it is applied correctly. The root system should be well developed and the plant actively growing. Limited watering 12–18 hours before application assists in better uptake and effectiveness.

Two-Spotted Spider Mites

Description and Life History

The two-spotted spider mite (TSSM) attacks many greenhouse crops. The 8-legged female adult is approximately 0.5 mm long with a rounded abdomen. The male is distinguished from the female by its smaller, narrower body and pointed abdomen. Adults range from pale yellow to orange to brown. The overwintering or diapausing stage is reddish orange. Diapause is induced in spider mites by day lengths of 12 hours and less, decreasing temperatures and the decreasing quality of food sources. During diapause, spider mites can tolerate very low temperatures. A short spell of heating is not sufficient to break its diapause.

Close examination of leaf undersurfaces shows mites to be very tiny moving dots. The two dark spots on the body of TSSM are the gut contents showing through the transparent body. After mating, each female mite lays about 6 pearly-white eggs per day. Over an average lifetime, a female lays 100 or more eggs on the undersurface of foliage. Newly hatched mites pass through the typical 6-legged larval stage and 8-legged protonymph and deutonymph stages. The last of these is an immobile resting stage, making it a very difficult target for miticides. The life cycle from egg to adult ranges from 23 days at 15°C to just 4 days at 32°C. Development is fastest under hot, dry conditions *(Plate 101).*

Damage

All active stages of the two-spotted spider mite feed by piercing the lower epidermis of the leaf with their sucking mouthparts. The feeding injury starts as a yellow "stippling." As mite numbers increase, the entire leaf appears stippled or light-coloured on the upper surface. Very heavily infested leaves become yellow and brittle, with obvious webbing on the leaves *(Plate 102).* If infestations proceed without control measures, the plants may die. Mite populations seem to increase dramatically at certain times of the year, since the life cycle varies considerably with temperature. Other factors, such as humidity and plant nutrition, are important and can be used to help reduce mite outbreaks.

Control Strategies

Conduct a proper cleanup between crops to reduce initial infestations in subsequent crops. Do this just before the overwintering or diapausing phase of the spider mites, because the diapausing mites hibernate in the ground, hollow stems, pipe fittings, cracks and crevices during the fall and winter months. The mites become active again during late winter and early spring. The red mite stages are generally pesticide-resistant, and predators will not feed on them readily. When the red post-diapausing mites are detected, use low-residual sprays on lightly infested leaves, and remove and destroy more heavily infested leaves.

Biological Control

The principal biological control agent available for spider mites is the predatory mite *Phytoseiulus persimilis.* Other biological control agents include the predatory mites *Amblyseius californicus* and *A. fallacis;* a ladybeetle, *Stethorus punctillum*; and the predatory mosquito-like midge *Feltiella acarisuga.*

Phytoseiulus persimilis

This predatory mite is about the same size as TSSM but is pear-shaped, pale salmon to bright orange, does not have TSSM's 2 spots and moves more rapidly on long legs. It feeds specifically on spider mites and does not hibernate.

Without spider mites, these predators die and new introductions are required. Adult predators feed on about 7 adults or 15–20 eggs per day. At 20°C, *P. persimilis* reproduces almost twice as fast as TSSM. Control with *P. persimilis* is most effective at 20–26°C. These predators do not thrive above 30°C or at humidities under 60%, seeking cooler, more protected areas lower down in the crop canopy. In contrast, TSSM thrive under these conditions.

Predators are available commercially, either mixed with vermiculite or on bean leaves. With either carrier, treat infested plants at the first sign of damage. Before releasing the predators, always ensure that they are alive and very active. Try to place a few predators onto every infested leaf.

Amblyseius californicus and *A. fallacis*

These predatory mites are amber-coloured and shaped like droplets, very similar in appearance to *A. cucumeris.* They attach whitish, oval eggs to hairs along the veins of the undersides of leaves. They can feed on other mites such as the carmine spider mite and can survive on pollen. They are also reported to tolerate high temperatures, low humidities and a range of pesticides.

Stethorus punctillum

This is a tiny, oval, convex, shiny, black ladybeetle. It lays white eggs singly on the undersides of leaves. The eggs turn blackish just before the larvae hatch. Newly hatched larvae are grey to blackish and have many long, branched hairs. Just prior to pupation, the entire larva turns reddish. Pupae are black and flattened, and the entire body is covered with yellow hairs. Newly emerged adults are reddish-orange for a few hours and then turn black. *Stethorus punctillum* is strictly a predator of plant-feeding mites and prefers the egg stage. It is reported to establish on pepper and cucumber crops but not on tomato crops.

Feltiella acarisuga

This predatory midge, also known as *Therodiplosis persicae,* resembles mosquitoes. The adult is able to fly and actively search for spider mites. It lays eggs alongside spider mite colonies. Orange-coloured larvae hatch from the eggs and can feed on all stages of spider mites. Larvae pupate next to the leaf veins in white cocoons. The life cycle varies with temperature, taking 2–4 weeks to complete. *Feltiella* will feed on the red diapausing mites on which *Phytoseiulus* will only reluctantly feed. Although establishment is variable, it has been reported to occur on all greenhouse crops, including tomato, under suitable conditions. *Feltiella* performs best under high humidity (>80% relative humidity) and in "hot spots." Note that use of sulphur can reduce the efficacy and survival of *Feltiella.*

Physical Control

Misting plants and maintaining relatively high humidities help suppress spider mite populations. For example, at 20°C and 36% relative humidity, female TSSM will lay about 7 eggs per day; at 95% humidity, about 30% fewer eggs are laid.

Chemical Control

Because of their great reproductive potential, two-spotted spider mites easily develop pesticide resistance. To effectively manage this pest using pesticides, observe these guidelines:

- Direct sprays to the underside of leaves where spider mites usually congregate.
- In areas of high mite density, the webs can protect the mites and the eggs found within and beneath the web. In this situation, use higher spray pressures to penetrate the web.
- Because of TSSM's high reproductive potential, use non-chemical control options as much as possible to minimize the development of pesticide resistance.

Tomato Russet Mites

Description and Life History

Plant species known to be hosts of the tomato russet mite (TRM) include tomato, petunia, morning glory, bell pepper, potato, nightshade, tobacco, field bindweed and eggplant. Tomatoes, however, are the preferred host and facilitate profuse development of this mite. Mites travel on infested plants by crawling and can move about 1.25 cm in 2 minutes. When the mites have fed on all the surrounding fresh, green tissue, they crawl to the tips of stems, leaves and hairs and wait there to grab onto whatever form of transportation — including wind, tools and clothing — comes along to carry them to another host.

Adults are yellowish-orange in colour and cone-shaped, with 2 pairs of legs. Adult females, which are the largest of the stages, are 200 microns (0.20 mm) long and 50 microns thick. Females each lay about 10–53 eggs among the hairs or in the tiny crevices found on the surface of stems, leaves and fruits. Adult females live for approximately 2–3 weeks and produce a generation in about 7 days under greenhouse conditions. These mites feed on the outermost layer of cells on the plant surface. The damaged cells oxidize, creating a bronzed appearance. Typically, damage starts on the main stem at about the base or mid-level of the plant and spreads upwards.

Growth and survival depend on the availability of green tissue. The TRM does not produce any special hibernating forms to survive winter conditions. Instead, it continues to reproduce as long as conditions are favourable. Laboratory experiments have shown that adults and some eggs will survive for at least 10 days when exposed to a constant temperature of 1°C, whereas exposure to a constant temperature of -5°C resulted in 100% mortality after 4 days.

Damage

The TRM is probably the least obvious of greenhouse pests, not being easily detected until it has multiplied to very high population levels. A magnification lens of at least 20X is required to see these mites. The earliest indication of TRM in a greenhouse tomato crop is a subtle bronzing of the stems and leaves *(Plate 103)*. Later symptoms include papery, brown leaves and bronzed fruit with many small cracks. The mites are rarely found in flowers and usually do not injure them. By the time TRM damage is observed in a crop, many neighbouring plants have accumulated significant populations despite the lack of apparent damage.

Control Strategies

Monitoring and Early Detection

Carefully check plants for feeding symptoms. Once these are detected, the grower can take appropriate measures that could include roguing or removing infested plants.

Cultural Control

A very important management strategy for TRM is to remove any potential host plants between crops in the greenhouse and in the immediate surroundings of the greenhouse. A thorough cleanup between crops and good weed control both inside and outside the greenhouse will help reduce the incidence and spread of TRM. Potatoes can also harbour TRM, so avoid planting them close to greenhouse crops.

Biological Control

The predatory mite *Neoseiulus (Amblyseius) fallacis* may have potential for managing TRM.

Cyclamen/Broad Mites

The cyclamen mite mainly attacks ornamental crops, but it also attacks field crops and shrubs. Broad mites attack a similar ornamental host range but also crops such as peppers, cucumbers, eggplant, potatoes and tomatoes.

Description and Life History

Adult cyclamen mites are the larger of the 2 species, being 0.75–1.0 mm long, while broad mites are less than 0.2 mm. The adult cyclamen mite varies in colour from milky white to yellowish brown and is elliptical in shape, whereas the broad mite can vary from translucent and colourless to pale brown, with a white stripe down the centre of its back. Adults of both species can be easily mistaken for each other, but their eggs are quite distinct. Eggs of the cyclamen mite are about 0.35–0.5 mm long and oval, with a smooth, opaque, white surface, whereas those of the broad mite are about 0.08 mm long, flattened and covered with 30–40 whitish bumps.

Optimum conditions for both mite species are 16–27°C and 80–90% RH. They can both complete a life cycle in 1–3 weeks, depending on temperature. Female cyclamen mites begin laying eggs within 2 days after emergence, and each female may lay 1–3 eggs per day, for a total of 12–16 eggs during her lifetime. These eggs are laid in moist, dark places, typically within the growing points of vegetable crops. Female broad mites lay 30–76 eggs on the leaf surface over an egg-laying period of 8–13 days. No diapause has been reported for either mite species, but they appear to overwinter as adults in protected locations either in greenhouses or outdoors.

Both mite species can be spread by windblown infested plant material, human transfer of infested plants or contact between infested plants. Male broad mites also transport inactive female larvae (quiescent nymphs or pupae) on their backs, usually moving upwards towards the plant's growing points. This arrangement facilitates mating as soon as the adult females emerge. Another major difference between these two species is that broad mites can be spread by attaching themselves to the legs of whiteflies and, to a lesser extent, to their antennae, whereas no such relationship has been reported for cyclamen mites. Transport of the broad mites by other pests such as thrips and aphids appears to be insignificant. Studies also suggest that certain species of whitefly, including those commonly found in greenhouse crops, are more efficient carriers than others.

Damage

Damage includes stunting, misshapen leaves on new growth *(Plates 104, 105)*, bronzing of the young stems and leaves, distorted young fruits, whitish or brown streaks on developing fruits and, sometimes, dieback of growing points. At first glance, these symptoms might be mistaken for herbicide drift or even some type of virus.

Control Strategies

Monitoring and Early Detection

Regular monitoring of the growing points of crops is the simplest method for detecting these mites. Any sign of abnormally reduced growth or bronzing on a single plant or a few adjacent plants is a signal for microscopic examination of affected tissues. Generally, these mite species avoid light, explaining why they are found in the growing points. Cyclamen mites can be observed in the young, developing buds, whereas broad mites are more often found on the undersides of young, developing leaves at the growing point. Infestations are usually concentrated on a few clumps of adjacent plants and specifically on new, young growth, gradually spreading out from the initial focus of infestation.

Cultural Control

This entails roguing or removing infested plant parts, as well as removing susceptible host crops and weeds in the greenhouse and its immediate surroundings.

Biological Control

Potential biocontrol agents for the broad mite are *A. swirskii, A. cucumeris* and *A. californicus.*

Aphids

Description and Life History

Aphids are small (2–3 mm), soft-bodied insects with long legs and antennae. A pair of tube-like structures called cornicles project from the posterior end. Colour patterns range between black, grey, red, yellow and green. Several species may infest greenhouses. The most common are the green peach aphid *(Myzus persicae) (Plate 106)*, the cotton or melon aphid *(Aphis gossypii)* and the potato aphid *(Macrosiphum euphorbiae)*. Another species that can cause leaf distortion in pepper crops is the glasshouse potato aphid *(Aulacorthum solani)*.

Adult aphids are predominantly wingless, although winged adults can develop if the population becomes too dense. This adaptation serves as a dispersal mechanism, allowing aphids to move into a greenhouse from outside or to spread rapidly within a greenhouse.

Aphids moult through a number of different stages before becoming adults. The cast-off skins left behind each time they moult are a visible sign of their presence.

In a greenhouse situation, all aphids are female and give birth to live young. These offspring can reproduce within 7–10 days. One aphid can give birth to 60–100 young over a 20-day period. Aphids can rapidly achieve very large populations.

Damage

Aphids pierce plant tissue with their mouthparts and suck out the sap, causing deformed leaves and flowers. They excrete a sugary, sticky substance called honeydew, which promotes the development of black, sooty mould fungus *(Plate 107)*. Some aphids can transmit viral diseases, such as cucumber mosaic virus in cucumber crops.

Control Strategies

When monitoring for aphids, check yellow sticky cards for winged adults. For non-winged aphids, inspect new foliage carefully and regularly to prevent large infestations. Spot-treat isolated infestations to prevent their spread to the rest of the greenhouse.

Biological Control

Several types of biological control agents are readily available: the predatory midge *Aphidoletes aphidimyza*, the parasitic wasp *Aphidius* spp. and ladybeetles or ladybugs *(Hippodamia convergens* and *Harmonia axyridis)*. *Aphidoletes* and ladybeetles are usually used to supplement the activity of *Aphidius* and to reduce aphid populations in "hot spot" areas.

Aphidoletes aphidimyza

In the adult stage, *A. aphidimyza* resembles small mosquitoes or fungus gnats. Females lay up to 200 eggs in their lifetime. Eggs are laid close to aphid colonies, so the orange-coloured larvae have a food source readily available on hatching.

Eggs usually hatch after 2–3 days. After 7–14 days in the larval stage, they drop to the floor to pupate. The pupal stage usually lasts about 2 weeks. Adult *A. aphidimyza* feed on honeydew, while larvae can kill 3–50 aphids per day. Under natural day lengths, *A. aphidimyza* enters diapause between September and March and thus is not effective during this period.

Aphidius spp.

This parasitic wasp does not enter diapause and is usually more effective during winter, early spring and fall. During summer, other parasitic wasp species can parasitize *Aphidius*, reducing its impact on aphid populations. Optimum conditions for *Aphidius* are 18–25°C and 80% RH. *Aphidius* completes its development from egg to adult in about 10 days at 25°C and 14 days at 21°C.

Several species of *Aphidius* are commercially available. *Aphidius matricariae* can parasitize about 40 aphid species, including the green peach aphid. *Aphidius colemani* is more effective against the cotton aphid but still works quite effectively against the green peach aphid. *Aphidius ervi* is the best choice against the potato aphid.

Hippodamia convergens

Both the adult and larval ladybeetles feed on aphids. Larvae can feed on a total of about 400 aphids, while adults feed on up to 5,000 aphids each. *H. convergens* enters diapause under short-day conditions. When day lengths are suitable, it must feed on aphids to maintain egg production. Eggs are torpedo-shaped and orange-coloured. They are laid in circular clusters on the underside of leaves and hatch in 2–5 days.

The larval stage lasts for about 3 weeks, after which they pupate. Adults emerge from pupal cases after 3–5 days. To increase the percentage of the ladybeetles remaining in the greenhouse, release them in late evening and sprinkle a sweet liquid (e.g., diluted pop) over them. The sweet liquid provides an immediate source of energy and water.

Harmonia axyridis

This ladybeetle is also known as the multi-coloured Asian ladybeetle, Asian ladybeetle, Japanese ladybeetle or Halloween ladybeetle. Adults are oval, convex and about 6 mm long. They are most commonly orange with black spots, but some are black with red spots. Eggs are yellow and laid in clusters underneath leaves. The larvae are usually blackish with bright yellow spots along their sides. Total time for development from egg to adult at 25°C is 16–20 days. Females live 2–3 months and lay several hundred eggs each during their lifetime. Adults and larvae are voracious feeders and are reported to consume approximately 50–100 aphids per day.

(Also see OMAFRA Factsheet *Aphids in Greenhouse Crops*, Order No. 06-081.)

Cabbage Loopers

Description and Life History

Cabbage loopers are pale green caterpillars with several wavy white lines running along the length of the body *(Plate 108)*. Loopers can be up to 4 cm long and characteristically move by forming a loop with their bodies. Tiny loopers hatch from pearly, white, round eggs the size of a pinhead, which are usually laid on the undersides of leaves. Loopers feed mainly on the undersides of leaves and excrete dark green frass (droppings) in the vicinity of the feeding area. This feeding or caterpillar larval stage lasts about 2 weeks, after which the mature larva pupates inside a webbed cocoon attached to the underside of a leaf. The pupa is light green at first, becoming increasingly darker as it matures. Pupation can also take place under the groundsheet plastic or in the ground along side walls. The adult emerges in about 2 weeks and is greyish brown with a silvery spot resembling the figure "8" on the middle of each front wing. The life cycle is completed in about 28 days.

Generally, cabbage loopers are not able to overwinter in Canada, and infestations start each year with the arrival of adults from the southern United States. However, if conditions are favourable, loopers are able to survive in greenhouses from one season to the next.

Damage

Damage by young loopers consists of small areas on the undersides of leaves that have been superficially chewed and scraped away. As the loopers increase in size, they cut through the plant tissue, leaving ragged holes between the leaf veins. The size of the holes is proportional to the maturity of the loopers. These caterpillars can also feed on fruits, but they are more often observed on the foliage. Most of the damage is carried out by the last 2 larval stages.

Control Strategies

Their initial presence can be detected using light traps or pheromone traps. Light traps are useful during cooler months, when the risk of attracting additional moth pests is lessened. Pheromone traps can be used to detect the presence of male moths. Principal control strategies include the following:

- proper sanitation between crops to remove any residual populations, thereby preventing early infestation of the new crop
- use of light traps to kill adults
- use of insect screens over vents and doorways to prevent adults from entering the greenhouse
- frequent applications of the bacterial insecticide *Bacillus thuringiensis* (DiPel, Foray), particularly to target the younger larval stages
- release of biological control agents such as the parasitic wasp *Trichogramma* spp., which attacks the egg stage of the cabbage looper, and another parasitic wasp, *Cotesia marginiventris*, which attacks the larval stage

Lygus Bugs

Description and Life History

The lygus bug is also commonly known as the tarnished plant bug. The adult is 5–6 mm long. It is flat, oval-shaped and greenish brown in colour, with a small Y-shaped yellow mark on its back *(Plate 109)*. The younger stages (nymphs) are light green and resemble aphids except in the fact that they move swiftly when disturbed. All stages of the lygus bug except the eggs have stylets used to pierce young or succulent plant parts to extract juices. They feed on a wide range of plant hosts including most vegetable and fruit crops and many weeds. Adults usually overwinter in protected areas in plant debris outdoors and emerge from these overwintering sites in early spring to seek out egg-laying sites. When they find a suitable plant host (including greenhouse peppers and cucumbers), the eggs are inserted into the plant tissue and nymphs hatch out after a few days. They undergo 5 nymphal stages, completing their life cycle in about 4 weeks, depending on temperature. Approximately 3 generations can be found outdoors in southwestern Ontario and perhaps a few more in greenhouses.

Damage

Lygus bugs feed on flowers and shoot tips. They cause damage by piercing the tissue and injecting saliva that kills or distorts the tissue. Such feeding results in the loss of growing points, flower abortion and distortion of new growth in developing leaves, flowers and fruits.

Loss of growing points characteristically results in the development of bushy plants (in peppers, for example) because of the simultaneous growth of side shoots. Yellow varieties of pepper appear to be particularly attractive to this insect.

Control Strategies

Monitoring and Early Detection

Monitoring for lygus bugs is best done using a combination of yellow sticky cards and crop inspection. Often they may be observed on the cards before they are detected in the crop. The first line of defence is to control weeds in the immediate greenhouse area, starting the fall before a crop is grown. This discourages the overwintering of nearby populations that serve as a source of infestation the following spring. Maintain a well-mowed 10-m strip surrounding the greenhouse. Use coarse insect screens over vents, door openings, etc. to prevent the entry of adult bugs.

Biological Control

Good populations of generalist predators such as *Orius* have been associated with suppression of lygus bugs. *Anaphesiole*, a parasitic wasp, attacks only the egg stage and is available for biological control. There are other biological control agents still on trial. These may be available in future for an expanded biological control program for lygus bugs.

European Corn Borers

Description and Life History

The larva is the damaging stage of the European corn borer (ECB). It is grey to tan in colour, with dark spots along the back and a brownish-black head *(Plate 110).* These caterpillars spend most of their life feeding within their host (e.g., pepper fruits). The final and 5th larval stage overwinters in corn debris outdoors in the fall and completes development to the adult stage the following spring. The adults are about 1.5–2.0 cm long and light brown with dark, wavy bands. They search for suitable hosts such as corn and peppers and lay eggs on the undersides of leaves in a mass of 5–50 eggs that appear as fine fish scales. Egg-laying is favoured by warm, calm evenings and overnight dew. Immediately after hatching, the tiny larva feeds very little or immediately spins a web from which it hangs until it finds a pepper fruit. At that point, the larva bores its way into the fruit, usually under the calyx. It grows inside the fruit, moulting 5 times. The final larval stage can either pupate within the fruit or bore its way out of the pepper and pupate outside the fruit. European corn borer infestations normally begin in spring, around May to early June. There are 2 generations of this borer in southwestern Ontario and 1 generation elsewhere in Ontario.

Damage

Of the major greenhouse crops (tomato, cucumber, pepper, lettuce), only pepper is attacked by ECB. Fruits are the target for feeding, whereas damage to leaves is insignificant or non-existent. The larva bores into the fruit and feeds on the internal portion of the fruit. In addition to the direct feeding damage, the entry holes facilitate eventual rotting and breakdown of the internal tissues of the fruit. Early infestation of pepper fruits may be difficult to detect because the caterpillars inconspicuously bore into the fruit under the calyx. However, their presence is indicated by premature colouring of the fruit and by the presence of light-brown droppings around the entrance hole *(Plate 111).*

Control Strategies

Monitoring and Cultural Control

Management of ECB begins with clearing overwintering sites such as cornfields and grassy areas during the fall. To monitor for ECB the following spring, use pheromone traps and black-light traps to detect the initial flight of the adults. Light traps attract both males and females, while pheromone traps attract only males.

Biological Control

The parasitic wasp *Trichogramma brassicae* has been used with some success in field corn trials. It is a tiny wasp that attacks only the egg stage and requires even distribution throughout the crop for maximum effectiveness. Its effectiveness in greenhouse peppers still has to be determined.

Physical Control

Coarse screens over vents, doorways and all openings can help to prevent adults from entering the greenhouse. Place ultraviolet light traps at least 10–20 m outside the greenhouse to attract and kill adult ECB. These traps require a timed power source and regular cleaning of the electrocution mechanism.

Fungus Gnats/Shoreflies

Description and Life History

The grey-to-black adult fungus gnat is about 3–4 mm long, with long legs, thread-like antennae and large compound eyes that meet above the base of the antennae *(Plate 112)*. The adult is a weak flier, frequently observed resting on the media surface. Each female lives about 10 days and lays about 150 oval, white eggs in the organic matter of the media. Eggs hatch in 2–7 days, depending on the temperature, producing white larvae that are 4–6 mm long.

The larvae have 12 abdominal segments and a distinctive shiny, black head. The larvae spin pupal cases and remain immobile in the soil for 4–6 days, after which adult flies emerge. As with most insects, fungus gnats become more active and reproduce more quickly at warmer temperatures. The life cycle can be completed in 21 days at 24°C or 38 days at 16°C.

Shoreflies, another common greenhouse pest, are often confused with fungus gnats. However, the adults are stouter than fungus gnats, they are stronger fliers and they have 5 clear spots on the wings. The larvae live in the growing media, like fungus gnats, but lack the distinctive black head capsule. They are likely to prefer moister conditions than fungus gnats and are often found in wet areas under benches, with both adults and larvae feeding on algae.

Damage

Although fungus gnats generally feed on decaying organic matter in the soil, they can also feed on the young roots of plants. This is especially true when gnat populations are high. They have occasionally been observed feeding on the youngest shoots of cucumbers. Root feeding by fungus gnats makes a plant susceptible to root diseases such as *Pythium* root rot. Fungus gnats have also been implicated in the spread of disease-causing organisms such as *Pythium*, *Fusarium*, *Verticillium* and *Rhizoctonia*. Shoreflies are not usually a threat to greenhouse crops, but they can feed on roots, creating the potential for disease infections.

Control Strategies

Sanitation inside the greenhouse and in the surrounding outside area is very important. Avoid overwatering and maintain good drainage to prevent water puddling. Fungus gnats and shoreflies thrive in moist conditions. Shorefly control requires controlling algae, either directly (by applying chemicals) or indirectly (by reducing the moisture necessary for algal growth or reducing the high light levels the algae need). In addition, the strategies listed below can be used.

Biological Control

Biological control agents include the predatory mites *Hypoaspis* spp.; *Steinernema feltiae*, a parasitic nematode; and the rove beetle.

Hypoaspis

Hypoaspis is a soil-dwelling, brown mite that feeds on fungus gnat eggs and larvae, algae, thrips pupae, springtails, nematodes and the larvae of various flies and beetles. *Hypoaspis* is a hardy mite that can live about 24 days without food. It is not affected by low light conditions and has a life cycle of about 9–11 days under greenhouse conditions.

Hypoaspis is found mainly in the top 1 cm of the growing media. It works best when applied to the media just after vegetable seedlings are planted. *Hypoaspis* is most effective if it is introduced when fungus gnat populations are still low or non-existent.

Atheta coriaria (rove beetle)

Atheta coriaria is a small, black, soil-dwelling beetle *(Plate 113)* about 3–4 mm long. It is very active, and both the adult and the 3 larval stages feed on fungus gnats (eggs and larvae) and thrips (pupae). It is produced and sold commercially but also occurs naturally and is often found in greenhouses where pesticide use is reduced. It should be used in a similar fashion to *Hypoaspis*, introduced into the crop early to control soil-dwelling pests.

Nematodes *(Steinernema feltiae)*

It is best to treat early and often, even under low pest pressure, to prevent fungus gnat populations from reaching damaging levels. However, *Steinernema feltiae* can also be used under higher population conditions. These nematodes enter the body openings of fungus gnat larvae and then release bacteria, which multiply and kill the larvae. Because nematodes may not adequately multiply within the bodies of fungus gnat larvae, use several consecutive nematode applications to achieve control. To use nematodes successfully:

- Constantly agitate the nematode stock solution during application to incorporate oxygen and to ensure the nematodes do not settle out. Settling will cause uneven nematode distribution and patchy pest control.
- Use the solution within 4 hours.
- Media temperatures should be 16–30°C.
- Remove all filters that are 50 mesh or finer from application equipment and nozzles.
- Do not exceed a pump pressure of 2,068 kPa (300 psi).
- Do not use application systems that have a nozzle aperture smaller than 0.5 mm.
- Never expose nematode suspensions to direct sunlight. This will destroy the bacteria within the bodies of the nematodes.
- Do not expose nematodes to a pH that is below 3 or above 8.

Before applying fungicides to media that have been treated with nematodes, make sure they are compatible with nematodes. Similarly, before applying fungicides to media that will be treated with nematodes, make sure the residual activity of fungicides will not interfere with the planned use of nematodes.

(Also see OMAFRA Factsheet *Fungus Gnats and Shoreflies of Greenhouse Crops*, Order No. 06-079.)

Tomato Pinworms

Description and Life History

The tomato pinworm (TPW) is a semi-tropical pest that can infest tomato crops in Ontario. Other suitable hosts for TPW are potatoes, eggplant and weeds such as nightshade and its relatives. The adult is a small, light-brown moth about 6 mm long. It is generally more active at night, laying most of its eggs on younger leaves during the first few nights of activity. Newly hatched larvae crawl on the leaf surface for a very short time before entering the leaf to start mining *(Plates 114, 115, 116)*. There are 4 larval stages, the first 2 of which are spent in the leaf. The 3rd and 4th stages may be found between 2 leaves stuck together, in a leaf that has been folded over, or inside fruit. Larvae characteristically enter the fruit just beneath the calyx. Mature larvae may either remain on the plant or drop to the ground to pupate. On the ground, pupation usually occurs within the top 15 cm of soil. Tomato pinworms do not diapause. Their development continues year round, although it slows during cold weather. Development time from egg to adult usually ranges between 19–70 days, depending on temperature. The life cycle is completed in 28 days at 24°C and can be as short as 19 days at 30°C.

Damage

Tomato pinworm inflicts damage by feeding on tomato leaves and fruit. The most common type of injury is caused by larvae tunnelling or mining in the leaves. Initially, the mine is long and narrow, but it later widens to become blotch-shaped. Older larvae may fold the leaf over itself or join 2 leaves together, between which they continue to feed, causing large blotches. In severe infestations, all leaves on a plant are attacked, giving the crop a burnt appearance. More direct damage is caused to the crop when the older larvae penetrate nearby fruit by burrowing under the calyx into the fruit. Very small pinholes are left at the points of entry, which are often marked by the presence of a small amount of frass (droppings). Points of entry under the calyx are inconspicuous and can easily be overlooked during packing. Larvae may also bore into the sides of tomato fruit in heavily infested crops.

Control Strategies

- Inspect all seedlings for larval feeding damage.
- Destroy all old infested plants and any debris from infested crops.
- Use pheromone traps or light traps, along with regular crop inspections, to monitor for the presence of adults. Note that pheromone traps attract only male TPW, whereas light traps attract both sexes of TPW and many other insect species as well.
- Hand-pick damaged leaves and destroy larvae within the mines.
- Destroy weeds and stray tomato seedlings inside and around the greenhouse.
- Install insect barriers over vents.

Potato Psyllids

Description and Life History

Potato psyllids have 3 life stages: eggs, nymphs and adults.

The eggs are very small, football-shaped, yellow to orange in colour and borne singly on very fine stalks, usually along leaf margins. A 10X hand-lens is necessary to see the eggs.

Nymphs are flattened and somewhat scale-like, with a fringe of short spines around the edge. Younger nymphs are pale brown, turning green with each successive molt. Nymphs are usually found on lower leaves and on lower leaf surfaces. When disturbed, they move quite readily. They secrete a white substance that looks like granulated sugar or salt, which collects on leaves beneath the feeding nymphs *(Plate 117).*

Adults, sometimes referred to as "jumping plant lice," look like small cicadas. They are about 2 mm long and may be greenish to black in colour, with a distinctive white band around the abdomen. Their clear wings are held in a roof-like position over their body. As the name suggests, they jump and fly readily when disturbed. Recently emerged adults are pale yellow to light green and later turn grey or black.

A mature female can lay more than 500 eggs over a typical period of 21 days. On average, the eggs take 15–30 days to develop into adults. Pysllids thrive at a temperature of 27°C, while temperatures below 15°C or above 32°C adversely affect their development and survival.

Damage

Like aphids and leafhoppers, potato psyllids suck plant sap through needlelike mouthparts. They feed in a manner similar to aphids, but instead of producing a shiny film of honeydew on the leaves, they produce a sugary exudate that resembles white powder. The nymphs are the damaging stage. While they feed they inject a toxin that causes a physiological condition known as "psyllid yellows." Feeding by this pest not only causes yellowing of the plant but can also result in loss of vigour and yield due to a combination of reduced fruit set and fruit size. Damage symptoms include stunting, chlorosis and purpling of leaves, distorted leaf growth and small, poor-quality fruit. Infestations of pepper crops by psyllids are reported to be less damaging because no yellowing occurs. However, the powdery deposits on the fruit must be washed off before they can be marketed.

Control Strategies

Monitoring

Carry out weekly inspection of plants to check for the powdery exudate and nymphs that can occur either on the upper or lower leaf surfaces. Yellow sticky cards hung close to the top of the plant canopy will also catch the winged black adults, which, to the naked eye, resemble winged aphids.

Physical Control

This entails removing infested leaves and provides a rapid means for reducing the population.

Biological Control

Some evidence indicates that the predatory bugs *Dicyphus hesperus* and *Orius insidiosus* and the parasitic wasp *Tamarixia triozae* may contribute to the suppression of psyllids. However, use of *Orius* may not be as useful on tomatoes because young *Orius* nymphs tend to get caught on the sticky hairs present on tomato plant surfaces.

Chemical Control

There are no pesticides in Ontario that are specifically recommended for psyllids.

Leafminers

Description and Life History

Two main species of leafminers are important to Ontario growers: the vegetable leafminer *(Liriomyza sativae)* and the serpentine leafminer *(Liriomyza trifolii).* The pea leafminer, *Liriomyza huidobrensis,* has also been found in Ontario and is a major pest in other parts of the world. Although the serpentine leafminer can complete development on tomatoes and cucumbers, it prefers chrysanthemums, *Gerbera* and *Gypsophila.* Conversely, the vegetable leafminer prefers tomatoes, cucumbers and celery but will attack chrysanthemums and other plants in the absence of its preferred host. The pea leafminer has a wider host range and can move into field-grown crops as well, including vegetable crops such as cole crops, lettuce and celery. The 3 species of leafminers are similar in appearance and biology.

The adult leafminer is a small fly, approximately 3 mm long, with black and yellow markings on the head and thorax. Adults become active at sunrise. Females feed on soft, succulent leaves by piercing the surface with their ovipositor and then lapping the liquid exuding from the wound.

Female flies begin laying eggs 12–24 hours after emerging from the pupa. They lay about 250 eggs during their approximately 30-day lifetime. Eggs are laid in about 1 out of 7 leaf punctures (or "stipples"). The optimal temperature for leafminer development is 30°C. At temperatures above or below 30°C, egg production declines considerably. After 2–4 days, eggs hatch and the larvae begin feeding ("mining") in the leaf tissue *(Plate 118).*

The larvae mature in 4–7 days in summer and then cut a hole in the leaf surface and drop to the ground. Pupation takes place within a few hours, in the plant media or on plastic sheeting (where used). Pupation can also occur on the leaves. The pupal stage may last 5–10 days in the summer and up to 90 days during periods of low temperature (10–12°C) and scarce food supply. This may account for the winter survival of leafminers around the inside perimeter of the greenhouse, although no adult leafminers are evident. From the pupae, a new generation of adult flies emerges.

There is considerable overlapping of stages of the insect life cycle within any greenhouse. The complete life cycle of the leafminer can be as short as 14 days at 30°C, increasing to 24 days at 20°C and 65 days at 14°C.

Damage

Leafminer feeding may indirectly affect yield by reducing the plant's photosynthetic area and by damaging water-conducting vessels, causing leaf desiccation and leaf drop.

Control Strategies

- Inspect all new plant material entering the greenhouse.
- Destroy infested seedlings, cuttings and plant parts.
- Monitor the crop for pests by using yellow sticky boards and regular crop inspections.
- Get rid of weeds inside and outside the greenhouse. Weeds such as lamb's-quarter, chickweed, dandelion, plantain, common mallow and nightshade are good hosts for leafminers.
- Do not over-fertilize the crop — excess nitrogen levels can increase aphid and leafminer problems.
- Detached leaves should be bagged and removed from the greenhouse as soon as possible. Leafminer larvae can complete their development in leaves even after they are removed from the plant.

Biological Control

Biological control agents include the parasitic wasps *Diglyphus isaea* and *Dacnusa sibirica. Diglyphus* is likely to be a better choice in summer, when its numbers may be supplemented by naturally occurring populations migrating into the greenhouse from outside. *Dacnusa* will perform better than *Diglyphus* over the winter.

Diglyphus isaea

Diglyphus is a small, black wasp with a metallic-green sheen and short antennae. After locating a mine, the female first paralyzes the leafminer and then inserts an egg through the leaf, placing it near the leafminer. It may deposit up to 5 eggs this way, laying about 60 eggs during its lifetime. The larva that hatches is initially colourless, then becomes yellow-brown and finally turns turquoise. Development time from egg to adult is about 11 days at 25°C. This is generally shorter than that of both the leafminer and *Dacnusa.*

Diglyphus can parasitize leafminers that have already been parasitized by *Dacnusa.* It becomes the dominant species during summer, when warm conditions favour its activity. The presence of short mines indicates *Diglyphus* activity, as the paralyzed leafminer stops feeding immediately.

Dacnusa sibirica

The adult is a small, black wasp that differs from *Diglyphus* in having long, flexible antennae and lacking the metallic-green sheen. Unlike *Diglyphus,* a female *Dacnusa* inserts an egg into the body of the leafminer. Each female lives for about 2 weeks, during which time she may lay up to 90 eggs.

Eggs hatch within 4 days, and the larvae mature within the leafminer pupae. Development time from egg to adult is about 2 weeks at 22°C. All *Dacnusa* development takes place within the leafminer's body; therefore, assessing parasitism is difficult.

Occasional Greenhouse Pests

Ants

Ants are easily recognized by their elbowed antennae and narrow waists. They range from 1.5–6 mm long.

Ants are attracted to sweet substances. In greenhouses where insect feeding has produced honeydew or where flowers have nectaries, ants may be a problem. They can also interfere with the normal activity of bumblebees where they are used for pollination. Treat all ant trails or nests located in or near the greenhouse. Flooding nests with insecticidal soap and using household boric acid baits can provide some control.

Caterpillars

Several different insects have caterpillar stages that damage greenhouse crops. These include leaf rollers, armyworms, cutworms, loopers, fruitworms, hornworms, leaf tier and stalk borers. The adult moths of these caterpillars are often attracted to greenhouse lights in the summer and will then lay eggs that hatch into the caterpillar pest.

Armyworms and cutworms feed directly on plant foliage and may cause considerable damage. Both insects are dark brown or grey with longitudinal stripes. Cutworms burrow into the soil during the day and come out to feed at night. Use insecticides recommended for caterpillars to bring armyworm and cutworm infestations under control.

Other caterpillars such as stalk borers bore into plant stems, making the pests more difficult to control.

Pheromone traps can be used to detect certain moth species, while light traps can be used to monitor a broader range of species. If these pests are detected early, apply controls immediately. Insect screens on vents help prevent all adult stages of the caterpillars from entering the greenhouse, and a good inside/outside weed control program will reduce potential infestation sites. The bacterial insecticide DiPel or Foray provides good control of loopers and most leaf-eating caterpillars that are not miners.

Grasshoppers

Grasshoppers are easily recognizable and occasionally invade greenhouses. They will feed on almost any vegetation and, in large numbers, can destroy plants. Grass and weeds near greenhouses may allow a grasshopper infestation to occur, usually in late summer and fall.

Root Nematodes

These are not a major problem in hydroponic vegetable production but are seen occasionally where poor greenhouse hygiene exists.

Plant parasitic nematodes are worm-like organisms less than 1 mm long that live in the root media. They are broadly divided into two groups: ectoparasites, which attack plants externally, and endoparasites, which spend at least part of their life cycle within the plant tissue. All parasitic nematodes have stylets through which they inject saliva into the plant tissue. The saliva causes most of the damage. It results in cell death or the proliferation of giant cells that produce galls. Nematodes cause damage mainly by reducing the ability of plants to absorb water and nutrients. Above-ground symptoms of nematode damage include weakened plants that wilt in the sun, yellow or pale-green leaves and stunted fruit or flowers.

Where nematocides are used between crops grown in soil, nematode infestations often recur because the chemicals do not penetrate sufficiently into the lower soil levels. Soils treated with nematocides should always be properly aerated to avoid subsequent plant damage.

Root-Lesion Nematode, **Pratylenchus penetrans** *(Cobb)*

This endoparasitic nematode is native to Ontario soils and can attack many floral and vegetable crops. All stages are thread-like and invisible to the naked eye. This nematode invades the outer layers of young roots, causing small brown-to-black elliptical lesions that merge to discolour the roots and kill them.

Northern Root-Knot Nematode, **Meloidogyne hapla** *(Chitwood)*

This is another endoparasitic nematode native to Ontario soils. It attacks almost all types of vegetable crops and many floral crops, particularly roses, African violets and geraniums. Early larval stages are thread-like and invisible, while later stages and adults range in shape from peanut-like to pearl-like and are just visible when dissected from the roots. This nematode invades roots and causes swellings, knots or galls and excessive root proliferation. Infested roots do not necessarily become discoloured unless attacked by bacteria and fungi.

Dagger Nematode, **Xiphinema diversicaudatum** *(Micoletzky)*

This ectoparasitic nematode is not native to Ontario and was introduced into greenhouses on plant stocks. Dagger nematodes prefer plants with woody roots and are more frequently associated with crops such as strawberry, grapes and roses. This nematode survives in the root crotches of the understock. One of the largest nematodes attacking plants, this 6-mm-long, thread-like roundworm can be seen on the roots with careful scrutiny. It feeds on young roots from the soil, causing galls similar to root-knot galls but somewhat larger. These galls are actually curved swellings in the root tip area, accentuated with the necrosis and shrivelling of roots above the galls.

Pin Nematode, **Paratylenchus projectus** *(Jenkins)*

This nematode is native to Ontario and can attack many floral and vegetable greenhouse crops. All stages of pin nematode are thread-like and invisible to the naked eye. This species is active in both fine-textured clay soils and coarse-textured sandy soils. The pin nematode does not enter roots but feeds at root tips by probing root hairs and surface cells. No specific root symptoms (such as galls or lesions) appear.

Southern Root-Knot Nematode, **Meloidogyne incognita** *(Kofoid and White)*

This endoparasitic nematode is not native to Ontario but has become persistent in the protected greenhouse environment. It cannot survive outdoors during winter. It attacks tomato, cucumber and several floral and foliage crops. Root damage and symptoms differ from those of the northern root-knot nematode. Plants damaged by the southern root-knot nematode have larger galls and lack fine root growths from the galls. Tomato leaves may show purpling on the underside (a symptom similar to phosphorus deficiency) or downward curling of leaf edges; affected tomato or cucumber plants wilt readily.

Slugs and Snails

Slugs are dark-grey, soft-bodied creatures, 1.3–10 cm long. They glide over plants, leaving a shiny trail. Slugs eat the foliage of most greenhouse plants, shredding the leaves, and they may completely destroy a plant.

Snails are similar in colour and appearance to slugs, except that a snail bears a noticeable shell. The shell varies in colour and markings and may be 1.3–5 cm in diameter. Snails are particularly injurious to seedlings and will eat holes in the flowers and leaves of many plants. An individual snail may lay up to 100 eggs, depending on the species. Slugs lay fewer eggs, which can endure long periods of dry conditions and then hatch when moist conditions return. Both slugs and snails need a damp environment and fairly humid air to survive. They avoid the sun and come out primarily at night or on cloudy days. During the day, slugs hide under boards and rocks or in other damp, shady places. If the air or substrate is dry, a snail can pull its entire body into its shell and remain dormant for up to 4 years.

Some growers have reported good control of slugs by using certain parasitic nematodes. Indirect control strategies for these organisms should focus on reducing their favoured habitat. These strategies include:

- removing boards, bricks, etc. that are in contact with the ground, or arrange these to permit proper air circulation around and under them
- maintaining a plant density that permits sunshine to penetrate to the ground level, provides good air circulation and allows the plant media to dry
- where a low plant density is inappropriate, using a ground cover that is unattractive to snails (e.g., rough-cut cedar chips or crushed eggshells)
- using sawdust and diatomaceous earth as a barrier, keeping in mind these must be dry to be effective

Various devices can trap or attract slugs and snails for subsequent destruction. Traps can be made using beer or a mixture of water and commercial yeast as an attractant. Inverted flowerpots with crushed snails or slugs placed underneath or inverted grapefruit halves are good devices for attracting slugs and snails.

Chemical controls involve baited pesticides that combine bran bait with metaldehyde. Metaldehyde is toxic, so make sure children and pets are not exposed to it. Prolonged use of baits is likely to produce a local bait-resistant population.

Sowbugs and Pillbugs

Sowbugs and pillbugs have grey, flattened, oval bodies up to 13 mm long with 7 pairs of legs. Sowbugs have 2 small, tail-like structures that the pillbugs lack. They are both small decomposers but occasionally feed on roots and tender plant parts, causing seedling damage. They feed at night and hide during the day, preferring dark, moist areas with abundant organic matter. Sterilizing soil and eliminating decaying plant material and moist areas will help prevent a buildup of these pests. Many strategies used for snail and slug control also suppress sowbug and pillbug populations.

Springtails

Springtails are tiny, wingless insects 2–6 mm long. They range in colour from white, grey or yellow to red, orange, purple, brown or mottled hues. Springtails are usually found on the surface of moist soil, in pots or within the soil. They have a spring-like apparatus at the end of the abdomen that allows them to spring into the air. Most springtails are scavengers, feeding on decaying organic matter, algae or fungi. Because they usually do not feed on living plant material, chemical controls are rarely necessary.

Striped Cucumber Beetles

Striped cucumber beetles are yellow-green beetles about 6 mm long. They have 3 longitudinal stripes. These beetles and a relative, the spotted cucumber beetle, carry the bacteria *Erwinia tracheiphila*, which causes bacterial wilt in cucumbers and related species such as melons and squash. Striped adult cucumber beetles overwinter outdoors under old leaves, old logs or trash. They emerge the following spring, mate and feed for several weeks and then lay orange-yellow eggs in the soil at the base of plants. Larvae usually hatch in 10 days and then feed on the roots of plants for 2–6 weeks. Fully grown larvae are about 9 mm long. Pupation takes place in the soil, and adults emerge after about 1 week. There is only 1 generation per year in Ontario.

The adult beetles damage plants by chewing on leaves, stems and fruits, but the greatest damage comes from the wilt-causing bacteria they often carry in their gut. The bacteria survive the winter in the gut of the overwintering beetles. In the spring, the beetles inoculate plants with the disease as they feed on plant tissue.

There is no control for the wilt once a plant is infected. Inoculated leaves generally wilt within 5–6 days, and the plant dies within 2 weeks. Striped cucumber beetles can also transmit cucumber mosaic virus. The best control comes from insect barriers installed over all greenhouse openings to exclude the adult beetles.

Symphylans

Symphylans are small, white creatures that resemble centipedes and are found under stones, in rotting wood and in moist soil high in decaying organic matter. They have slender, white bodies 1–5 mm long, 10–12 pairs of legs and long antennae. (In contrast, centipedes have 15 pairs of legs.) While centipedes are beneficial predators that prey on many insects, symphylans can feed on the roots of plants. On many crops, the damage appears as tiny, black marks on the roots where a hemispherical piece of tissue has been scooped out. Injured roots become stubby, and the plant becomes stunted. The damage caused by symphylans provides entry points for root-rotting diseases.

Vertebrate Pests

Rats and mice may be very destructive in the greenhouse. They feed on almost any food source and can cause damage by gnawing and burrowing.

Norway rats and field mice are the most common vertebrate inhabitants of greenhouses. Baits containing rodenticides such as chlorophacinone, diphacinone, warfarin and zinc phosphide can give some control. The first 3 chemicals are anticoagulants, and multiple doses of them are usually required. Zinc phosphide is not an anticoagulant and is more acutely toxic — a single dose can kill the pest. Ensure that the toxic baits are placed in covered stations where pets cannot get them.

To minimize the development of rodenticide resistance, particularly to the anticoagulants, always adopt other control measures:

- store all potential food material in tight-fitting containers
- use many traps where there are signs of activity, placing 1 trap every 2–3 m along walls
- set traps at right angles to the wall, with the bait and trigger facing the wall
- handle traps with gloves to avoid contaminating them with human smells
- try different baits, such as peanut butter mixed with oats; raisins; gumdrops; any other sticky food material; or cotton (which provides nesting material)

Weed Control

Control of weeds inside and outside the greenhouse is an important part of any pest management program. Weeds can provide a refuge for insect pests and act as a reservoir for diseases. A 10-m strip of carefully maintained lawn around and between greenhouses will also decrease the danger of invasion by insects and diseases from outside. Use fescue grasses for lawn plantings around the greenhouse as they are the grasses least preferred by western flower thrips.

Herbicide application, cultivation and hand weeding are the most practical methods of controlling weeds in and around greenhouses. However, other, less labour-intensive methods include steaming and soil fumigation.

Herbicides

OMAFRA Publication 75, *Guide to Weed Control* contains information on herbicides registered for use in Ontario. Treatments listed in the publication are subject to extensive field trials and observation on farms.

If herbicides are used outside the greenhouse, there is potential for crop damage if they are used incorrectly. Take the following precautions to minimize spray drift into the greenhouse:

- **Turn off fans to avoid drawing herbicides into the greenhouse.**

- **Close vents before spraying,** and then spray only very early in the day to prevent greenhouse temperatures from rising excessively. Delay opening of the vents for at least 30–60 minutes after spraying is completed.
- **Apply herbicides only when wind speed is below 11 km/hr.** High winds will increase spray drift, causing droplets to be carried further away and thereby increasing the chance of drift entering the greenhouse.
- **Use nozzles that minimize spray drift.**
- **Use a sprayer equipped with spray guards.** Guards attached to the nozzle will minimize spray drift and direct sprays to the target.
- **Set the sprayer to increase droplet size.** A smaller droplet size will increase spray drift, whereas increasing the size and/or decreasing sprayer pressure will decrease spray drift.
- **If possible, use wipe-on applications.** This technique will minimize or eliminate drift.

Read the information on chemicals, safety precautions, calibrations and care and use of sprayers in OMAFRA Publication 75, *Guide to Weed Control.* Where unwanted herbicide residues remain in the soil, apply activated charcoal to reduce the problem. The rate varies depending on the type of chemical contaminant and its concentration. A usual range is 0.5–1.5 kg/100 m^2.

See OMAFRA Publication 835, *Crop Protection Guide for Greenhouse Vegetables* for more detailed information on precautions with pesticide use.

14. Appendices

Appendix A. OMAFRA Greenhouse Vegetable Staff

Gillian Ferguson
Greenhouse Vegetable IPM Specialist
Greenhouse and Processing Crops Research Centre
2585 County Road 20
Harrow, ON N0R 1G0
Tel: 519-738-1258
Fax: 519-738-4564
Email: gillian.ferguson@ontario.ca

Shalin Khosla
Greenhouse Vegetable Specialist
Greenhouse and Processing Crops Research Centre
2585 County Road 20
Harrow, ON N0R 1G0
Tel: 519-738-1257
Fax: 519-738-4564
Email: shalin.khosla@ontario.ca

A complete list of Ontario Ministry of Agriculture, Food and Rural Affairs advisory staff is available on the OMAFRA website at www.ontario.ca/crops.

Agricultural Information Contact Centre
Provides province-wide, toll-free technical and business information to commercial farms, agri-businesses and rural businesses
1 Stone Road West
Guelph, ON N1G 4Y2
Tel: 1-877-424-1300
Fax: 519-826-3442
Email: ag.info.omafra@ontario.ca

Appendix B. Diagnostic Services

Samples for disease diagnosis, insect or weed identification, nematode counts and *Verticillium* testing can be sent to:

Pest Diagnostic Clinic
Laboratory Services Division
University of Guelph
95 Stone Road West
Guelph, ON N1H 8J7
Tel: 519-767-6256
Fax: 519-767-6240
Email: pdc@lsd.uoguelph.ca

Payment must accompany samples at the time of submission. Submission forms are available at www.labservices.uoguelph.ca/units/pdc/.

Fee schedule

To obtain information on the fee schedule, visit www.labservices.uoguelph.ca/units/pdc/ or phone the Pest Diagnostic Clinic at 519-767-6256.

Submitting Plant Samples for Disease Diagnosis or Identification

Sample Submission Forms

Forms can be downloaded from the University of Guelph Laboratory Services' Pest Diagnostic Clinic website at www.labservices.uoguelph.ca/units/pdc/. Carefully fill in all of the categories on the form.

Choose a complete, representative sample showing early symptoms. Submit as much of the plant as is practical, including the root system, or several plants showing a range of symptoms. If symptoms are general, collect the sample from an area where they are of intermediate severity. Completely dead material is usually inadequate for diagnosis.

With plant specimens submitted for identification, include at least a 20–25 cm sample of the top portion of the stem with lateral buds, leaves, flowers or fruits in identifiable condition. Wrap plants in newspaper and put in a plastic bag. Tie the root system off in a separate plastic bag to prevent the roots from drying out and the soil from contaminating the leaves. Do not add moisture, as this encourages decay in transit. Cushion specimens and pack them in a sturdy box to avoid damage during shipping. Avoid leaving specimens to bake or freeze in a vehicle or in a location where they could deteriorate.

Delivery

Deliver to the Pest Diagnostic Clinic as soon as possible by first class mail or by courier at the beginning of the week.

Submitting Insect Specimens for Identification

Collecting Samples

Place dead, hard-bodied insects in vials or boxes and cushion them with tissues or cotton. Place soft-bodied insects and caterpillars in vials containing alcohol. Do not use water, as this results in rot. Do not tape insects to paper or send them loose in an envelope.

Place live insects in a container with enough plant material to feed them during transit. Be sure to write "live" on the outside of the container.

UNIVERSITY of GUELPH LABORATORY SERVICES

95 Stone Road West
Guelph, ON N1H 8J7
Tel: (519) 767-6256
Fax: (519) 767-6240
Web: www.uoguelph.ca/pdc

Pest Diagnostic Clinic

SAMPLE SUBMISSION FORM

LABORATORY USE ONLY: **LS Form: SubP01/04/03** **Pg. 1 of 1**
Rec'd: By:__________ **Date Received:** __________
Delivered By: ☐ **Mail** ☐ **Courier** ☐ **In-Person**
LS Sample No: __________ **to** __________
Payment Rec'd: $__________ **Receipt #:**__________

Submitted By:			Owner (if different from submitter):		
Business Name (if applicable):			Business Name (if applicable):		
Street:			Street:		
City:	Prov:	Postal Code:	City:	Prov:	Postal Code:
Tel: ( ) -	Fax: ( ) -		Tel: ( ) -	Fax: ( ) -	
Email:			Email:		

Unless otherwise indicated, report and invoice will be sent to submitter
Report to: ☐ Submitter ☐ Owner Required Report Format: ☐ Fax ☐ E-Mail ☐ Mail
Invoice to: ☐ Submitter ☐ Owner Quotation #: ________ Purchase Order / U of G G/L code:____________

Services Required: ☐ Nematode Count ☐ Nematode Count from Roots ☐ SCN Cyst & Egg Count ☐ Plant Disease Diagnosis ☐ Insect Identification ☐ Plant Identification ☐ Verticillium Count

Plant or Host Affected:		Cultivar/Variety:	Grower/Field sample #:
		Location of Plant (i.e. greenhouse, field, orchard, garden, etc.):	
Size of Planting:	% of Plants Affected:	Symptoms First Appeared in Past: ☐ Days ☐ Weeks ☐ Months ☐ Years	Degree of Injury: ☐ Severe ☐ Moderate ☐ Light
Cropping History:		Future Crop:	

Describe the problem in detail (i.e. symptoms, plant parts affected, distribution of symptoms):

Were chemicals applied? Please specify type of product(s) used and date(s) of application:

Additional comments and specific requests:

Additional Sheet(s) Attached: ☐

Appendix C. Other Contacts

AGRICULTURE & AGRI-FOOD CANADA RESEARCH CENTRES

www.agr.gc.ca/index_e.php

Greenhouse and Processing Crops Centre

2585 County Road 20
Harrow, ON N0R 1G0
Tel: 519-738-2251

Southern Crop Protection and Food Research Centre

1391 Sandford Street
London, ON N5V 4T3
Tel: 519-457-1470

Delhi Research Farm

Box 186 Schafer Road
Delhi, ON N4B 2W9
Tel: 519-582-1950

Vineland Research Farm

4902 Victoria Avenue North
Vineland, ON L0R 2E0
Tel: 905-562-4113

CANADIAN FOOD INSPECTION AGENCY REGIONAL OFFICES (PLANT PROTECTION)

www.inspection.gc.ca/english/toce.shtml

Belleville

345 College Street East
Belleville, ON K8N 5S7
Tel: 613-969-3333

Brantford

625 Park Road North, Suite 6
Brantford, ON N3T 5P9
Tel: 519-753-3478

Hamilton

709 Main Street West, Suite 101
Hamilton, ON L8S 1A2
Tel: 905-572-2201

London

19-100 Commissioners Road East
London, ON N5Z 4R3
Tel: 519-691-1300

Ottawa District

38 Auriga Drive, Unit 8
Ottawa, ON K2E 8A5
Tel: 613-274-7374, ext. 221

St. Catharines

395 Ontario Street, Box 19
St. Catharines, ON L2N 7N6
Tel: 905-937-8232

Toronto

1124 Finch Avenue West, Unit 2
Downsview, ON M3J 2E2
Tel: 416-665-5055

UNIVERSITY OF GUELPH

Main Campus

Guelph, ON N1G 2W1
Tel: 519-824-4120
www.uoguelph.ca

Alfred Campus

Alfred, ON K0B 1A0
Tel: 613-679-2218
Fax: 613-679-2423
www.alfredc.uoguelph.ca

Kemptville Campus

Kemptville, ON K0G 1J0
Tel: 613-258-8336
Fax: 613-258-8384
www.kemptvillec.uoguelph.ca

Ridgetown Campus

Ridgetown, ON N0P 2C0
Tel: 519-674-1500
www.ridgetownc.on.ca

Department of Plant Agriculture

www.plant.uoguelph.ca

Department of Plant Agriculture, Guelph

50 Stone Road West
Guelph, ON N1G 2WI
Tel: 519-824-4120, ext. 56083
Fax: 519-763-8933

Department of Plant Agriculture, Simcoe

1283 Blueline Road, Box 587
Simcoe, ON N3Y 4N5
Tel: 519-426-7127
Fax: 519-426-1225

Department of Plant Agriculture, Vineland

Box 7000, 4890 Victoria Avenue North
Vineland Station, ON L0R 2E0
Tel: 905-562-4141
Fax: 905-562-3413

Lab Services Division

www.uoguelph.ca/labserv
P.O. Box 3650, 95 Stone Road West
Guelph, ON N1H 8J7
Tel: 519-767-6299
Fax: 519-767-6240

Trace Organics and Pesticides

Tel: 519-767-6485
Fax: 519-767-6240

Pest Diagnostic Clinic

Tel: 519-767-6256
Fax: 519-767-6240

VINELAND RESEARCH AND INNOVATION CENTRE

4890 Victoria Avenue North
Vineland Station, ON L0R 2E0
Tel: 905-562-0320
Fax: 905-562-0084
www.vinelandontario.ca

Appendix D. Soil Testing Labs in Ontario

Contact the individual laboratory for a listing of greenhouse-related analytical tests available.

Laboratory Name	Address	Telephone/Fax	Contact
A & L Canada Laboratories Inc.	2136 Jetstream Road London, ON N5V 3P5	tel: 519-457-2575 fax: 519-457-2664 aginfo@alcanada.com	Greg Patterson Ian McLachlin
Accutest Laboratories A Bodycote Testing Group Company	8-146 Colonnade Road Ottawa, ON K2E 7Y1	tel: 613-727-5692, x317 fax: 613-727-5222 lorna.wilson@bodycote.com	Lorna Wilson
Agri-Food Laboratories	503 Imperial Road, Unit #1 Guelph, ON N1H 6T9	tel: 519-837-1600 1-800-265-7175 fax: 519-837-1242 lab@agtest.com	Trish Kelly Jack Legg
FoReST Laboratory	955 Oliver Road BB1005D Thunder Bay, ON P7B 5E1	tel: 807-343-8639 fax: 807-343-8116 soilslab@lakeheadu.ca	Claire Riddell Joel Symonds
Stratford Agri-Analysis	1131 Erie St., Box 760 Stratford, ON N5A 6W1	tel: 519-273-4411 1-800-323-9089 fax: 519-273-2163 info@stratfordagri.ca	Keith Lemp Mark Aikman
University of Guelph, Laboratory Services	University of Guelph P.O. Box 3650 95 Stone Road West Guelph, ON N1H 8J7	tel: 519-767-6299 fax: 519-767-6240 info@lsd.uoguelph.ca	Nick Schrier

Appendix E. Ontario Ministry of the Environment Regional Contact Information

Region/County	Address	Telephone/Fax
Central Region Toronto, Halton, Peel, York, Durham, Muskoka, Simcoe	5775 Yonge Street 8th Floor Toronto, ON M2M 4J1	Tel: 416-326-6700 Toll-Free: 1-800-810-8048 Fax: 416-325-6345
West-Central Region Haldimand, Norfolk, Niagara, Hamilton-Wentworth, Dufferin, Wellington, Waterloo, Brant	Ontario Government Building 119 King Street West 12th Floor Hamilton, ON L8P 4Y7	Tel: 905-521-7640 Toll-Free: 1-800-668-4557 Fax: 905-521-7820
Eastern Region Frontenac, Hastings, Lennox & Addington, Prince Edward, Leeds & Grenville, Prescott & Russell, Stormont/Dundas & Glengarry, Haliburton, Peterborough, Kawartha Lakes, Northumberland, Renfrew, Ottawa, Lanark, District of Nipissing (Twp. of South Algonquin)	1259 Gardiners Road Unit 3 PO Box 22032 Kingston, ON K7M 8S5	Tel: 613-549-4000 Toll-Free: 1-800-267-0974 Fax: 613-548-6908
Southwestern Region Elgin, Middlesex, Oxford, Essex, Kent, Lambton, Bruce, Grey, Huron, Perth	733 Exeter Road London, ON N6E 1L3	Tel: 519-873-5000 Toll-Free: 1-800-265-7672 Fax: 519-873-5020
Northern Region (East) Manitoulin, Nipissing, Parry Sound, Sudbury, Algoma (East), Timiskaming, Sault Ste. Marie	199 Larch Street Suite 1201 Sudbury, ON P3E 5P9	Tel: 705-564-3237 Toll-Free: 1-800-890-8516 Fax: 705-564-4180
Northern Region (West) Algoma (West), Cochrane, Kenora, Rainy River, Timmins, Thunder Bay	435 James Street South Suite 331 Thunder Bay, ON P7E 6S7	Tel: 807-475-1205 Toll-Free: 1-800-875-7772 Fax: 807-475-1745
Standards Development Branch	Pesticides Section 40 St. Clair Avenue West 7th Floor Toronto, ON M4V 1L5	Tel: 416-327-5519 Fax: 416-327-2936
Approvals Branch	Pesticides Licensing 2 St. Clair Avenue West 12A Floor Toronto, ON M4V 1L5	Tel: 416-314-8001 Toll-Free: 1-800-461-6290 Fax: 416-314-8452

Appendix F. The Metric System

Metric Units

Linear Measures (length)

10 millimetres (mm)	=	1 centimetre (cm)
100 centimetres (cm)	=	1 metre (m)
1,000 metres (m)	=	1 kilometre (km)

Square Measures (area)

100 m × 100 m = 10,000 square metres (m^2)	=	1 hectare (ha)
100 hectares (ha)	=	1 square kilometre (km^2)

Cubic Measures (volume)

Dry Measure

1,000 cubic millimetres (mm^3)	=	1 cubic centimetre (cm^3)
1,000,000 cubic centimetres (cm^3)	=	1 cubic metre (m^3)

Liquid Measure

1,000 millilitres (mL)	=	1 litre (L)
100 litres (L)	=	1 hectolitre (hL)

Weight-Volume Equivalents (for water)

1 gram (g) = 0.001 kilograms (kg)	=	1 millilitre (mL) = 0.001 litres (L)
10 grams (g) = 0.01 kilograms (kg)	=	10 millilitres (mL) = 0.01 litres (L)
100 grams (g) = 0.10 kilograms (kg)	=	100 millilitres (mL) = 0.10 litres (L)
500 grams (g) = 0.50 kilograms (kg)	=	500 millilitres (mL) = 0.50 litres (L)
1,000 grams (g) = 1.00 kilogram (kg)	=	1,000 millilitres (mL) = 1.00 litre (L)

Weight Measures

1,000 milligrams (mg)	=	1 gram (g)
1,000 grams (g)	=	1 kilogram (kg)
1,000 kilograms (kg)	=	1 tonne (t)
1 milligram/kilogram (mg/kg)	=	1 part per million (ppm)

Dry–Liquid Equivalents

1 cubic centimetre (cm^3)	=	1 millilitre (mL)
1 cubic metre (m^3)	=	1,000 litres (L)

Metric Conversions

5 millilitres (mL)	=	1 teaspoon (tsp)
15 millilitres (mL)	=	1 tablespoon (tbsp)
28.5 millilitres (mL)	=	1 fluid ounce (fl oz)

Application Rate Conversions

Metric to Imperial (approximate)

millilitres per hectare (mL/ha) × 0.015	=	fluid ounces per acre (fl oz/ac)
litres per hectare (L/ha) × 0.71	=	pints per acre (pt/ac)
litres per hectare (L/ha) × 0.36	=	quarts per acre (qt/ac)
litres per hectare (L/ha) × 0.09	=	gallons per acre (gal/ac)
grams per hectare (g/ha) × 0.015	=	ounces per acre (oz/ac)
kilograms per hectare (kg/ha) × 0.89	=	pounds per acre (lb/ac)
tonnes per hectare (t/ha) × 0.45	=	tons per acre (T/ac)

Imperial to Metric (approximate)

fluid ounces per acre × 70	=	millilitres per hectare (mL/ha)
pints per acre × 1.4	=	litres per hectare (L/ha)
quarts per acre × 2.8	=	litres per hectare (L/ha)
gallons per acre × 11.23	=	litres per hectare (L/ha)
ounces per acre × 70	=	grams per hectare (g/ha)
pounds per acre × 1.12	=	kilograms per hectare (kg/ha)
tons per acre × 2.24	=	tonnes per hectare (t/ha)

Liquid Equivalents (approximate)

Litres/Hectare		*Gallons/Acre*
50	=	5
100	=	10
150	=	15
200	=	20
250	=	25
300	=	30

Dry Weight Equivalents (approximate)

Grams/Hectare		*Ounces/Acre*
100	=	1 ½
200	=	3
300	=	4 ¼
500	=	7
700	=	10
Kilograms/Hectare		*Pounds/Acre*
1.10	=	1
1.50	=	1 ¼
2.00	=	1 ¾
2.50	=	2 ¼
3.25	=	3
4.00	=	3 ½
5.00	=	4 ½
6.00	=	5 ¼
7.50	=	6 ¾
9.00	=	8
11.00	=	10
13.00	=	11 ½
15.00	=	13 ½

Handy Metric Conversion Factor

litres per hectare × 0.4 = litres per acre

kilograms per hectare × 0.4 = kilograms per acre

Conversion Tables — Metric to Imperial

Length		
1 millimetre (mm)	=	0.04 inches (in.)
1 centimetre (cm)	=	0.40 inches (in.)
1 metre (m)	=	39.40 inches (in.)
1 metre (m)	=	3.28 feet (ft)
1 metre (m)	=	1.09 yards (yd)
1 kilometre (km)	=	0.62 mile (mi)

Area		
1 square centimetre (cm^2)	=	0.16 square inches (sq in.)
1 square metre (m^2)	=	10.77 square feet (sq ft)
1 square metre (m^2)	=	1.20 square yards (sq yd)
1 square kilometre (km^2)	=	0.39 square mile (sq mi)
1 hectare (ha)	=	107,636 square feet (sq ft)
1 hectare (ha)	=	2.5 acres (ac)

Volume (dry)		
1 cubic centimetre (cm^3)	=	0.061 cubic inches (cu ft)
1 cubic metre (m^3)	=	35.31 cubic feet (cu ft)
1 cubic metre (m^3)	=	1.31 cubic yards (cu yd)
1,000 cubic metres (m^3)	=	0.81 acre-foot (ac ft)
1 hectolitre (hL)	=	2.8 bushels (bu)

Volume (liquid)		
1 millilitre (mL)	=	0.035 fluid ounces (fl oz)
1 litre (L)	=	1.76 pints (pt)
1 litre (L)	=	0.88 quarts (qt)
1 litre (L)	=	0.22 gallons (Imp.) (gal)
1 litre (L)	=	0.26 gallons (U.S.) (gal)

Weight		
1 gram (g)	=	0.035 ounces (oz)
1 kilogram (kg)	=	2.21 pounds (lb)
1 tonne (t)	=	2,205 pounds (lb)
1 tonne (t)	=	1.10 short tons

Pressure		
1 kilopascal (kPa)	=	0.15 pounds per square inch (psi)

Speed		
1 metre per second (m/s)	=	3.28 feet per second (ft/sec)
1 metre per second (m/s)	=	2.24 miles per hour (mph)
1 kilometre per hour (km/h)	=	0.62 miles per hour (mph)

Temperature		
°F	=	(°C × 9/5) + 32

Conversion Tables — Imperial to Metric

Length		
1 inch (in.)	=	2.54 centimetres (cm)
1 foot (ft)	=	0.30 metres (m)
1 yard (yd)	=	0.91 metres (m)
1 mile (mi)	=	1.61 kilometres (km)
Area		
1 square foot (sq ft)	=	0.09 square metres (m^2)
1 square yard (sq yd)	=	0.84 square metres (m^2)
1 acre (ac)	=	0.40 hectares (ha)
Volume (dry)		
1 cubic yard (cu yd)	=	0.76 cubic metres (m^3)
1 bushel (bu)	=	36.37 litres (L)
Volume (liquid)		
1 fluid ounce (Imp.) (fl oz)	=	28.41 millilitres (mL)
1 pint (Imp.) (pt)	=	0.57 litres (L)
1 gallon (Imp.) (gal)	=	4.55 liters (L)
1 gallon (U.S.) (gal)	=	3.79 litres (L)
Weight		
1 ounce (oz)	=	28.35 grams (g)
1 pound (lb)	=	453.6 grams (g)
1 ton (T)	=	0.91 tonnes (t)
Pressure		
1 pound per square inch (psi)	=	6.90 kilopascals (kPa)
Temperature		
°C	=	(°F – 32) × 5/9

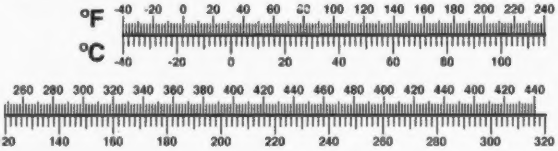
Abbreviations

%	= per cent (by weight)	km/h	= kilometres per hour
cm	= centimetre	kPa	= kilopascal
cm^2	= square centimetre	L	= litre
e.g.	= for example	m	= metre
g	= gram	m^2	= square metre
ha	= hectare	mL	= millilitre
kg	= kilogram	mm	= millimetre
km	= kilometre	m/s	= metres per second
		t	= tonne

Calculating Parts per Million (ppm)

1 ppm	=	1 g active ingredient per 1,000 L water

TEMPERATURE



For exact values the formula is:
Fahrenheit to Celsius: subtract 32 from number of °F, then multiply by 5/9.
Celsius to Fahrenheit multiply °C by 9/5 then add 32.

Colour Plates

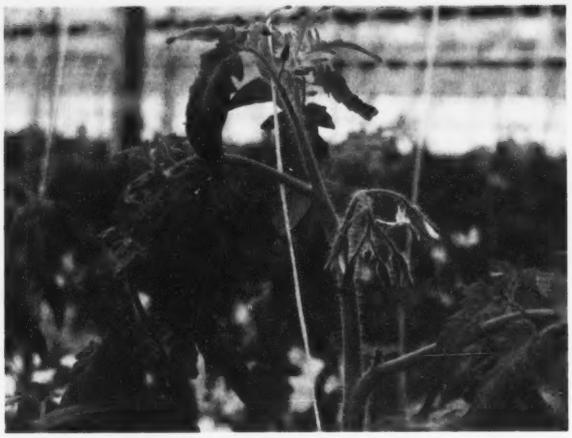


Plate 1. A balanced tomato plant.

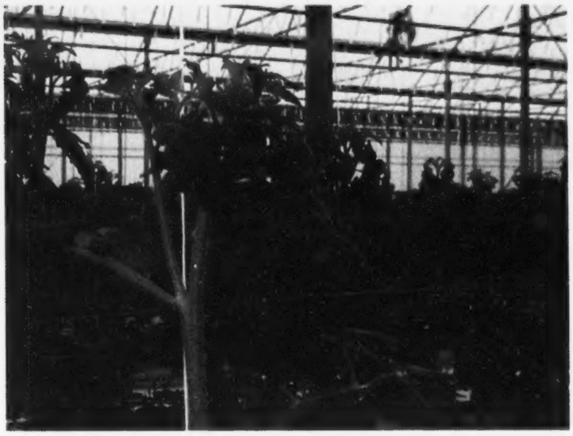


Plate 2. A vegetative tomato plant.

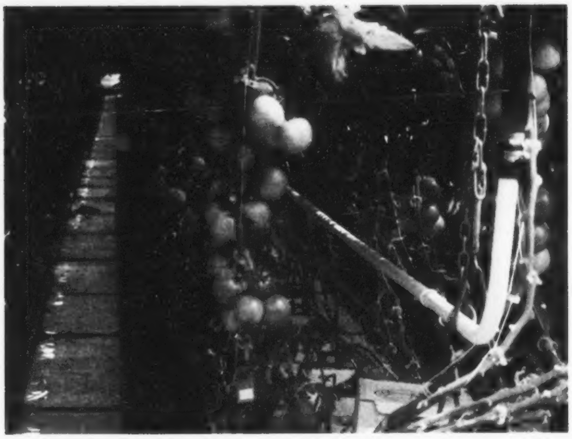


Plate 3. Grow pipe located at maturing fruit.

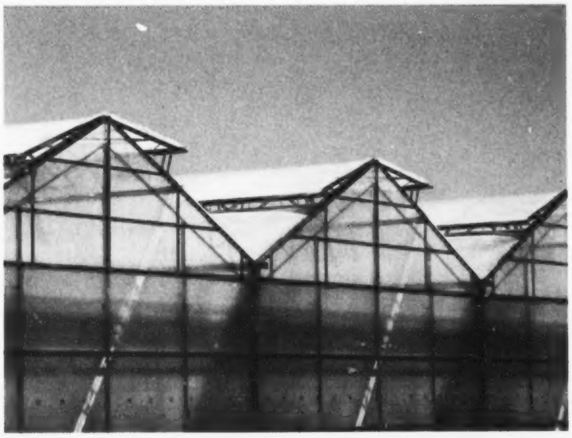


Plate 4. A modern greenhouse with higher gutter height and peak-roof profile.

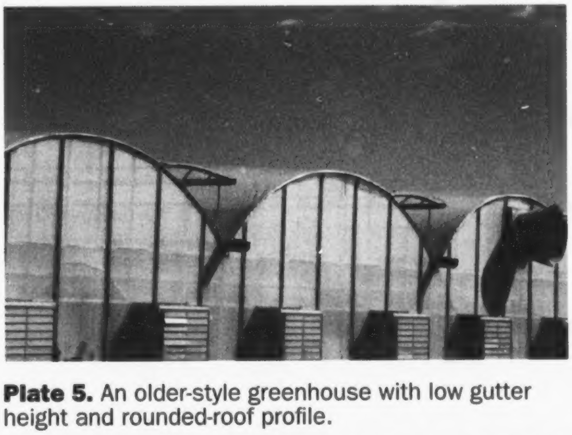


Plate 5. An older-style greenhouse with low gutter height and rounded-roof profile.

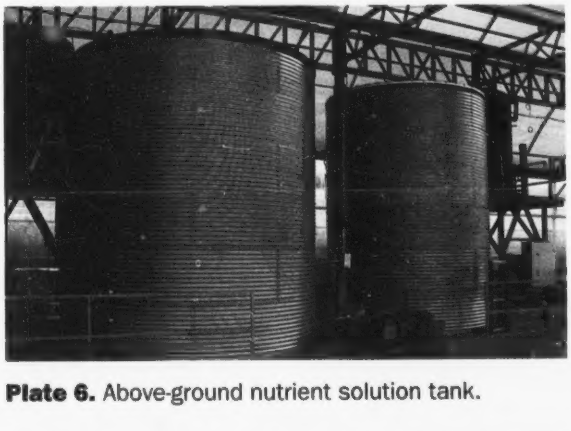


Plate 6. Above-ground nutrient solution tank.

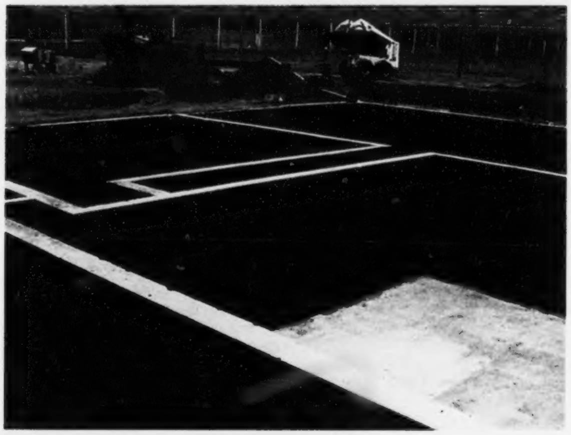


Plate 7. Below-ground nutrient solution tank.

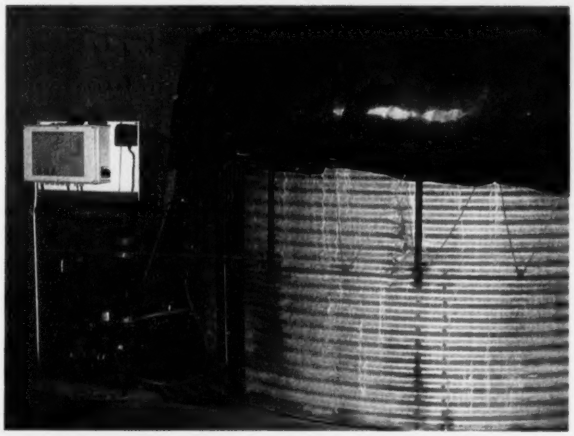


Plate 8. Lava filtration system.

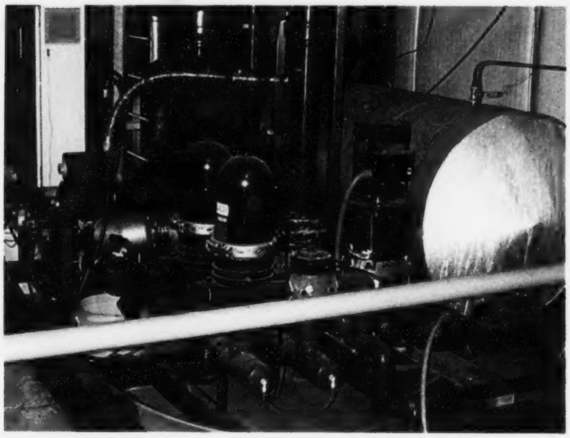


Plate 9. Heat pasteurization unit.

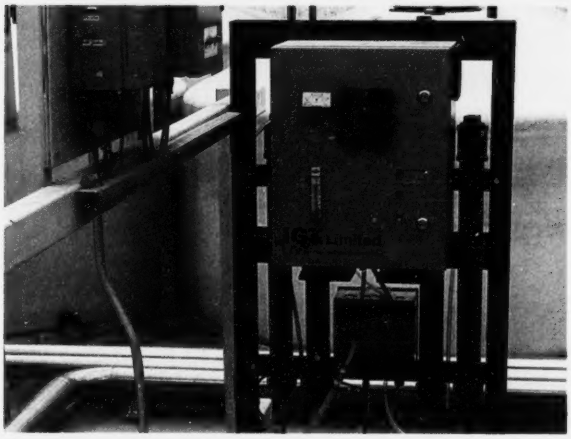


Plate 10. Ozonation unit.

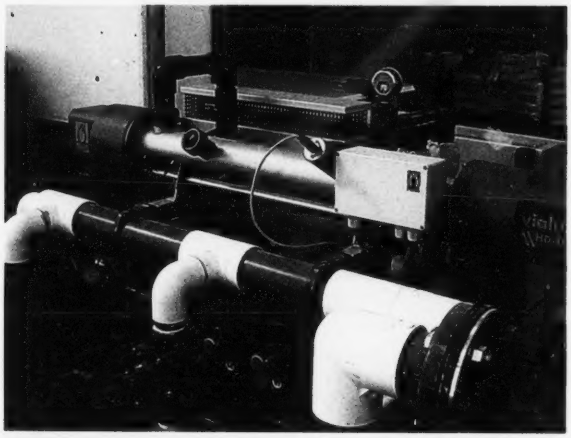


Plate 11. Ultraviolet filtration.

Plate 12. Basic setup for rockwool production.

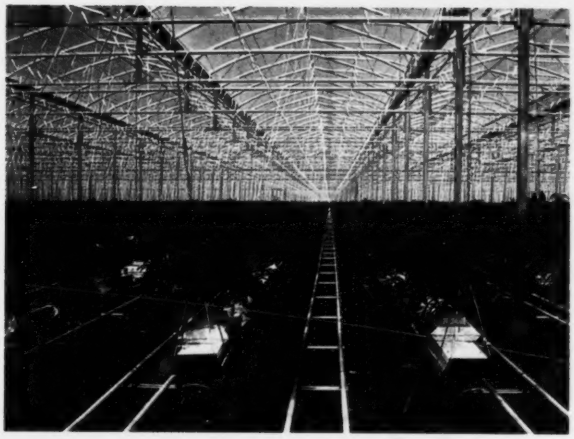


Plate 13. Raised trough system.

Plate 14. Rockwool slabs ready for steaming.

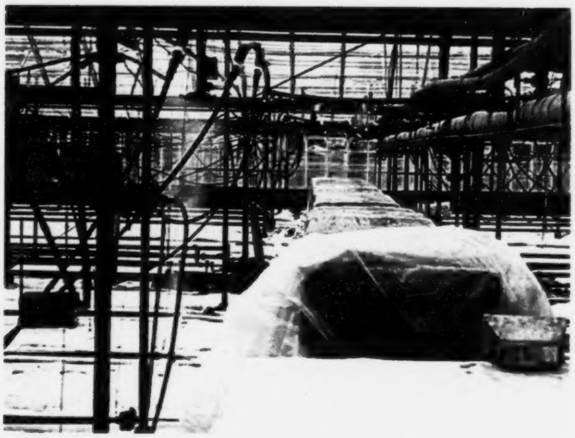


Plate 15. Steaming of rockwool slabs.

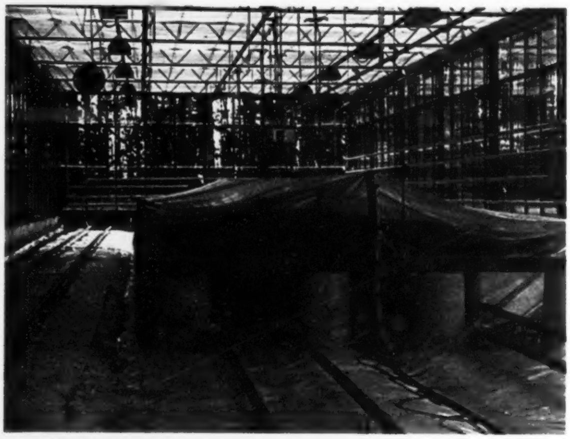


Plate 16. Setup for seed germination.

Plate 17. Transplant raising.

Plate 18. Rootstock ready for grafting.

Plate 19. Rootstock with top removed.

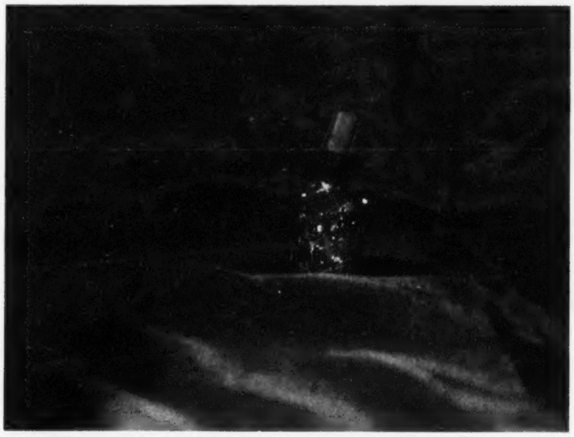


Plate 20. Rootstock with clip added.

Plate 21. Scion placed in clip.

Plate 22. Finished graft topped at cotyledon leaf.

Plate 23. Finished graft with two stems ready to transplant.

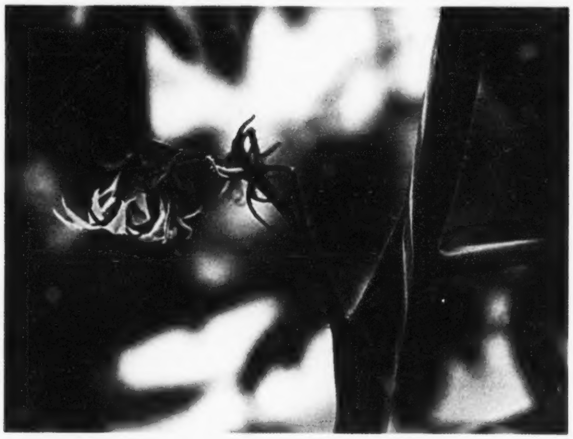


Plate 24. Flower development — stalk slightly too long.

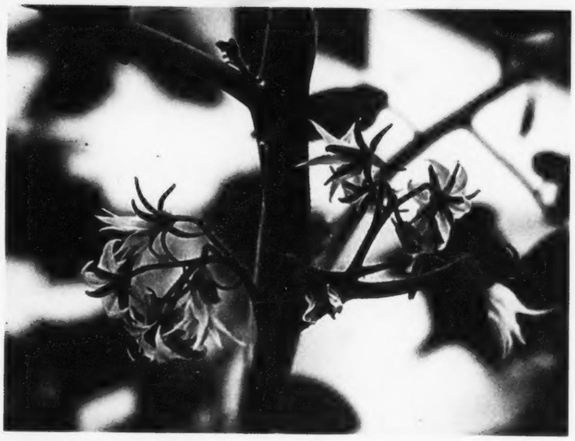


Plate 25. Split cluster due to low night temperature at the early bud development stage.

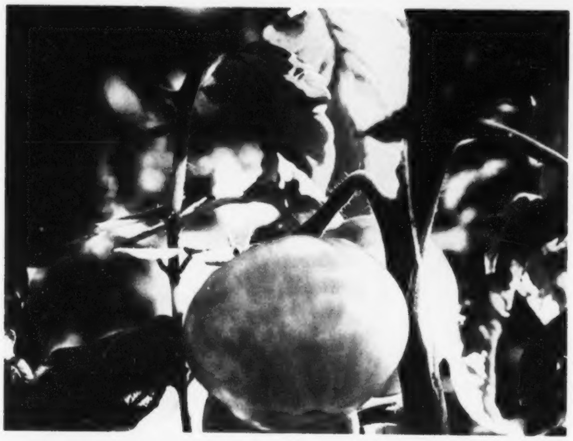


Plate 26. Tomato truss too long, resulting in kinking of stalk.

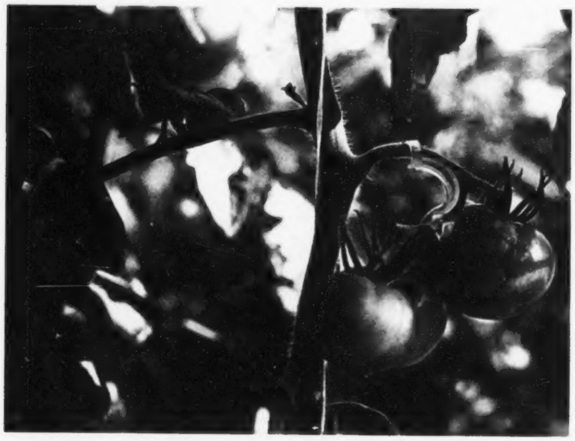


Plate 27. Truss support to prevent kinking.

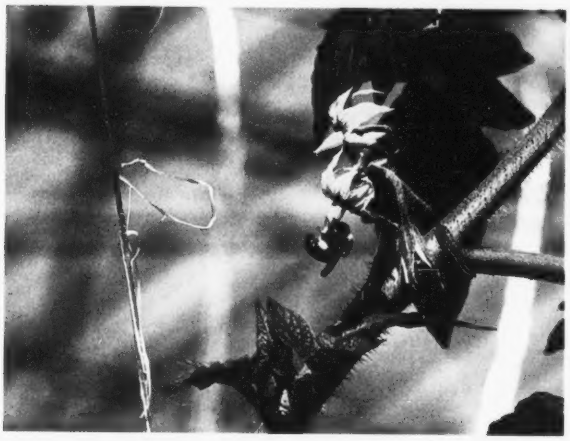


Plate 28. Bumblebee visiting tomato flower.

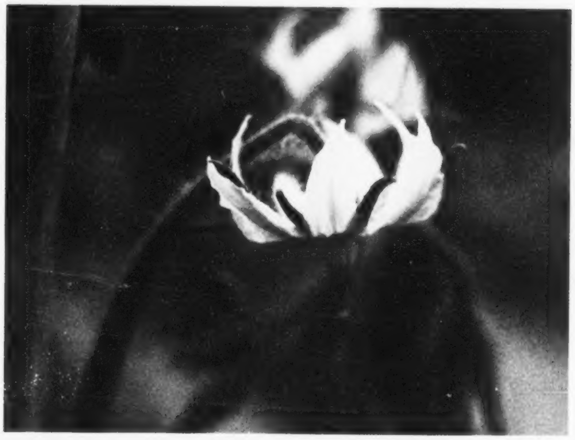


Plate 29. Tomato flower showing marks caused by bumblebee visit — an indication of good pollination.

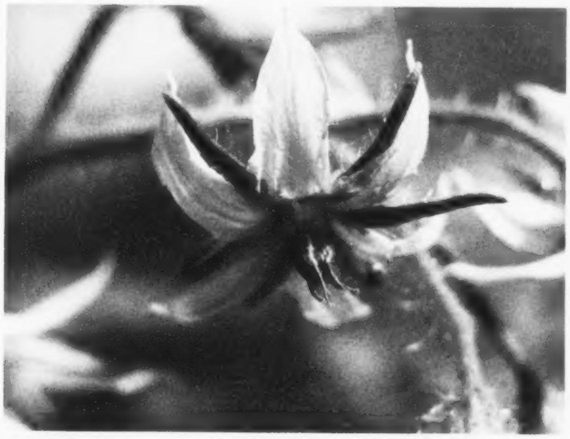


Plate 30. Tomato flower damaged by too many bumblebee visits.

Plate 31. Cucumber ready for transplanting.

Plate 32. Young pepper plant showing split stem and first flower (king flower) on the first level.

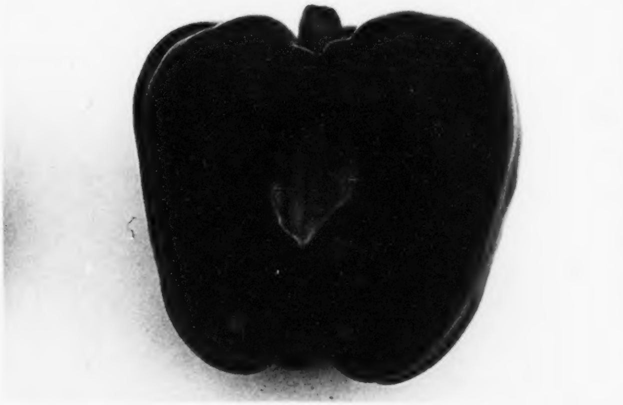


Plate 33. Sunscald.

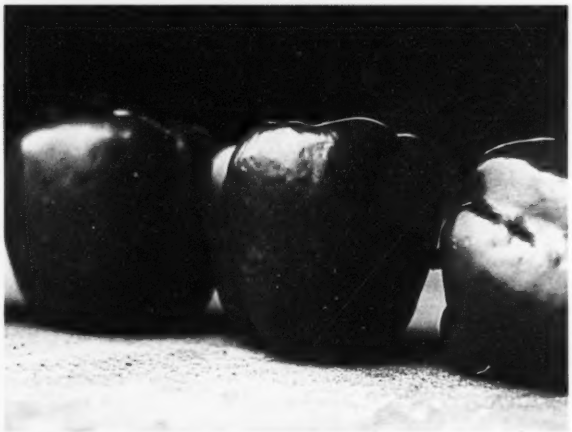


Plate 34. Sunscald on pepper surface due to poor canopy and direct light on fruit surface.

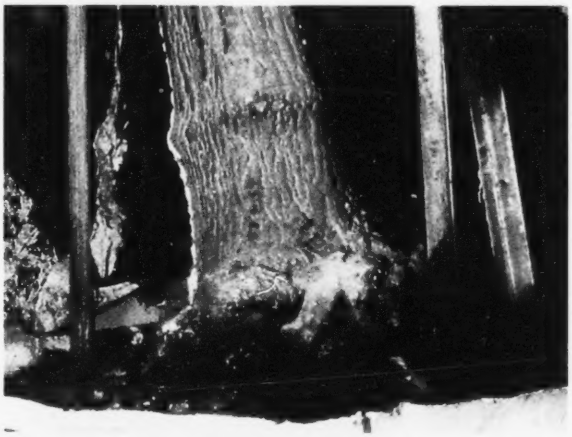


Plate 35. Elephant's foot as a result of damage from the accumulation of salts at the base of the plant.

Plate 36. Multi-stem eggplant to maintain plant balance and control height.

Plate 37. Strong eggplant flower for rapid fruit production.

Plate 38. High humidity in the greenhouse causing water condensation. This increases the incidence of gummy stem blight, Botrytis grey mould and Penicillium stem rot.

Plate 39. Damping-off.

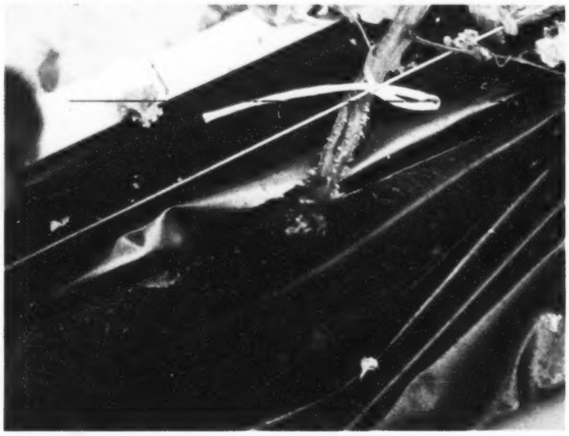


Plate 40. Fusarium crown and root rot.

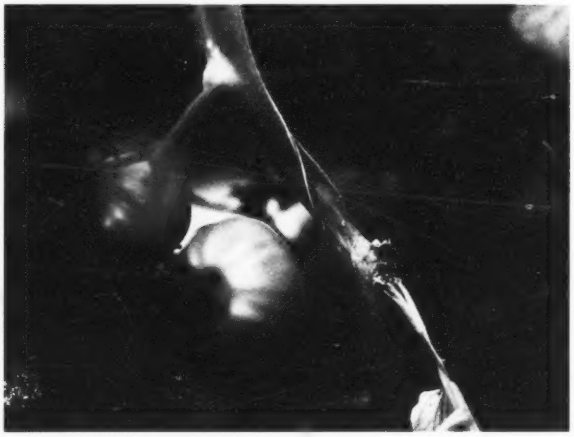


Plate 41. Grey mould.

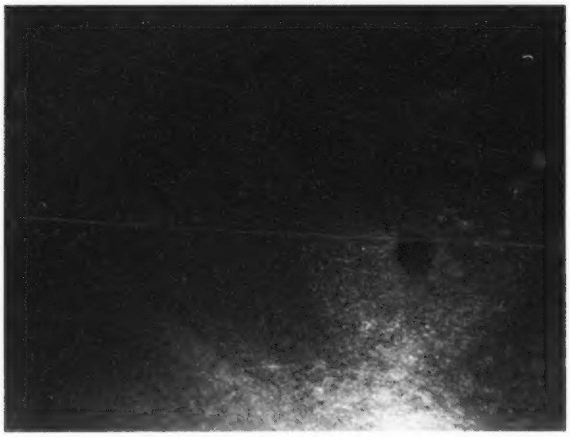


Plate 42. Grey mould ghost spot.

Plate 43. Powdery mildew on tomato leaf.

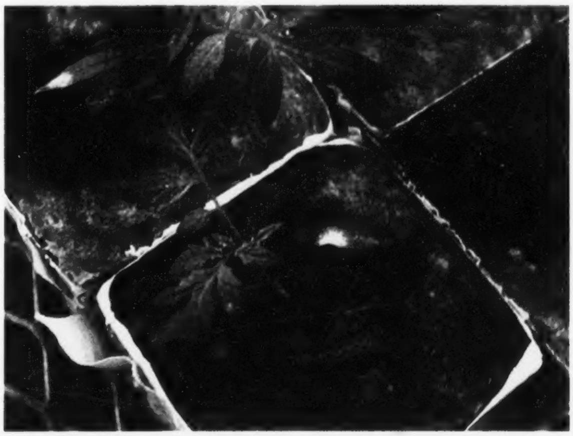


Plate 44. Powdery mildew on tomato seedlings.

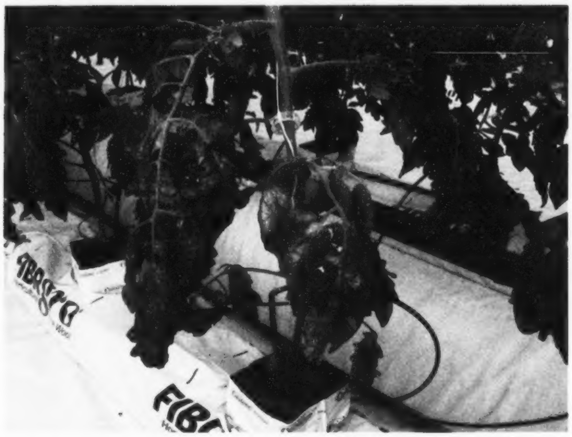


Plate 45. Large paper-like symptoms due to late blight on tomato plant.

Plate 46. Dark, greasy lesion due to late blight on tomato fruit.

Plate 47. Bacterial canker — one-sided wilt.

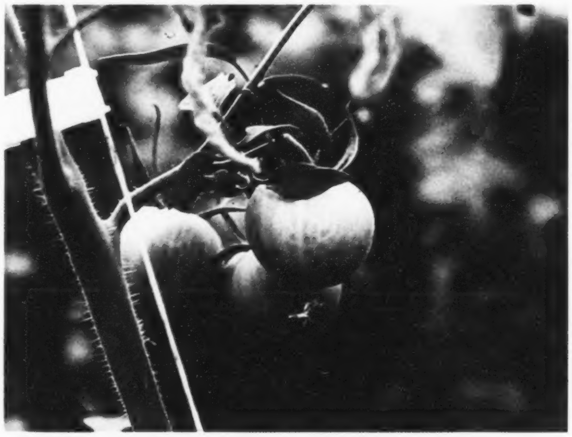


Plate 48. Bacterial canker — fruit mottling.

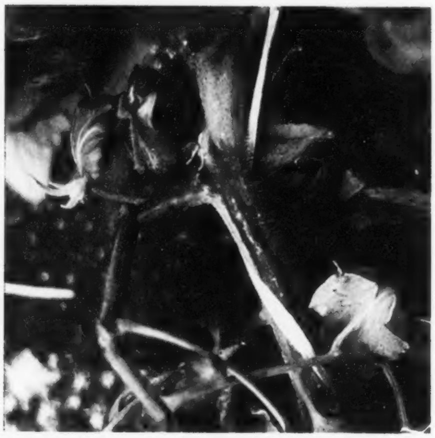


Plate 49. Bacterial stem rot.

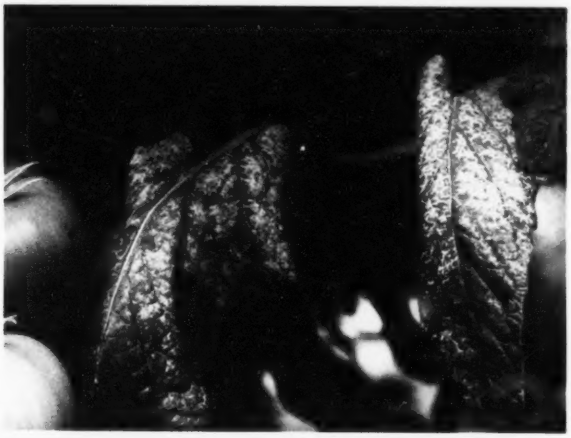


Plate 50. Leaf symptoms of Pepino mosaic virus in tomato.

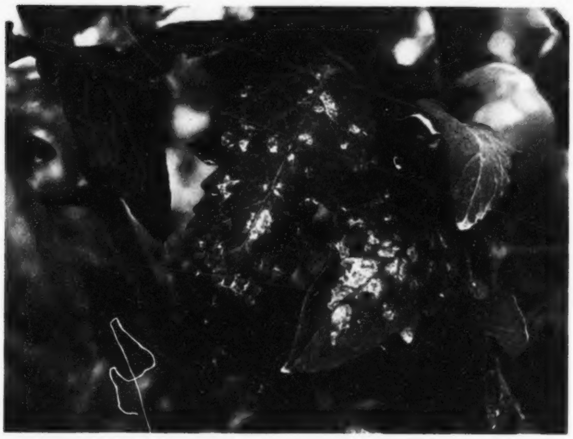


Plate 51. Leaf symptoms of Pepino mosaic virus in tomato.

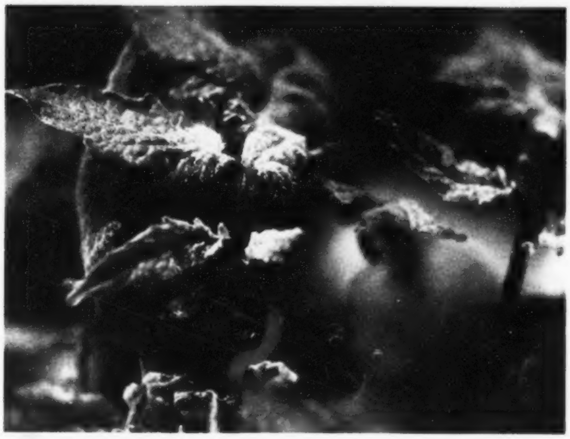


Plate 52. Leaf symptoms of Pepino mosaic virus in tomato.

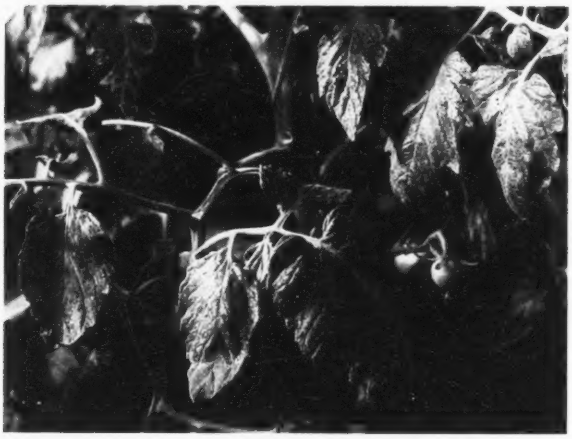


Plate 53. Leaf symptoms of tomato spotted wilt virus in tomato.

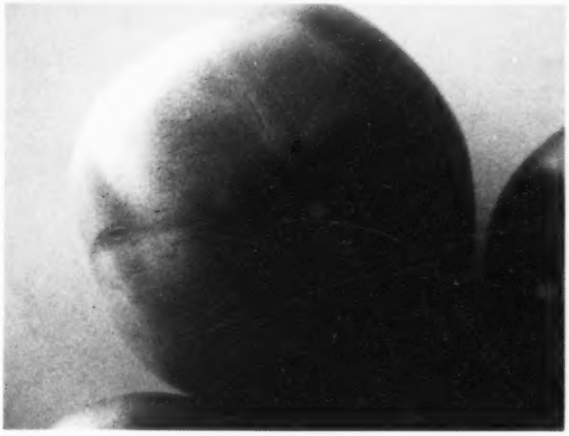


Plate 54. Blossom end rot.

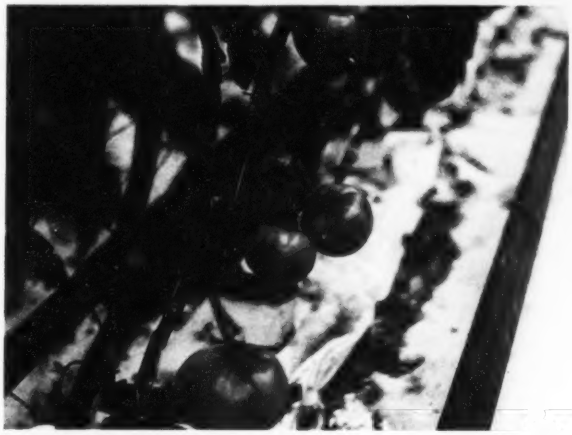


Plate 55. Blotchy ripening due to low potassium.

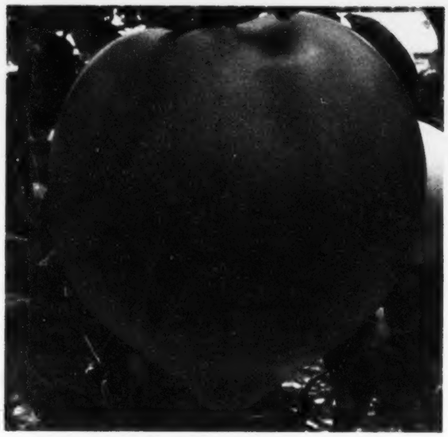


Plate 56. Tomato pointy fruit.

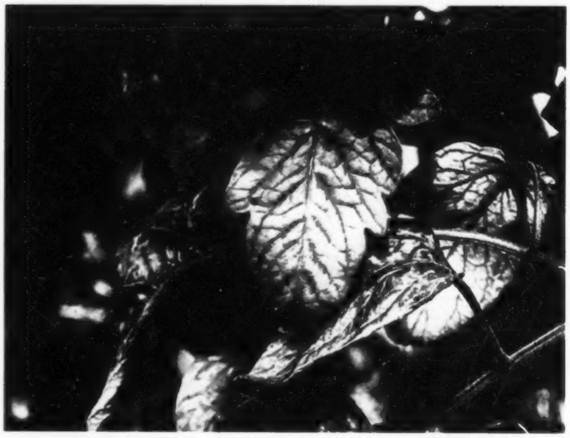


Plate 57. Magnesium deficiency.

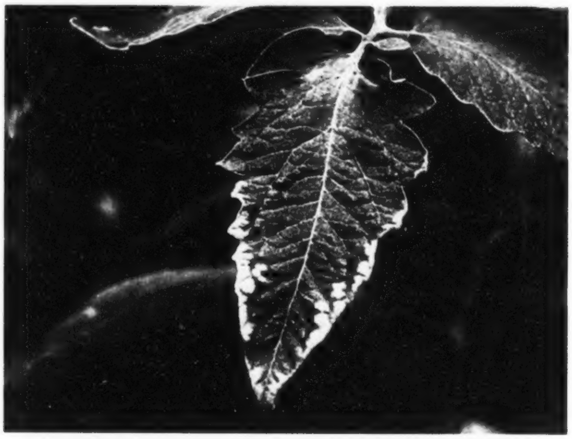


Plate 58. Environmental stress resulting in poor calcium and potassium movement to leaf's edge.

Plate 59. Iron deficiency.

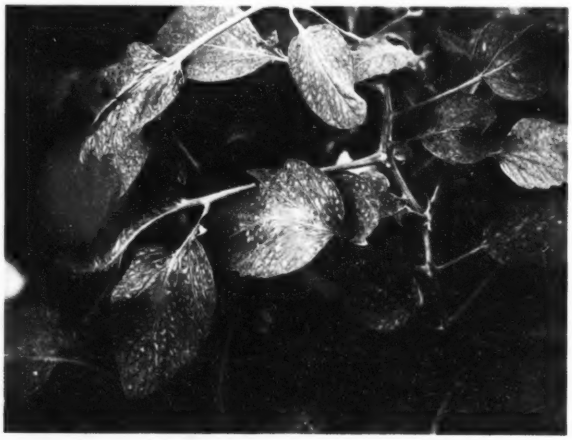


Plate 60. Iron deficiency due to poor root environment as a result of overwatering.

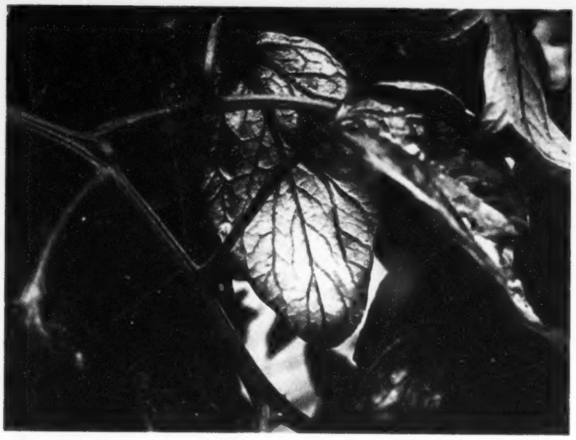


Plate 61. Boron deficiency.

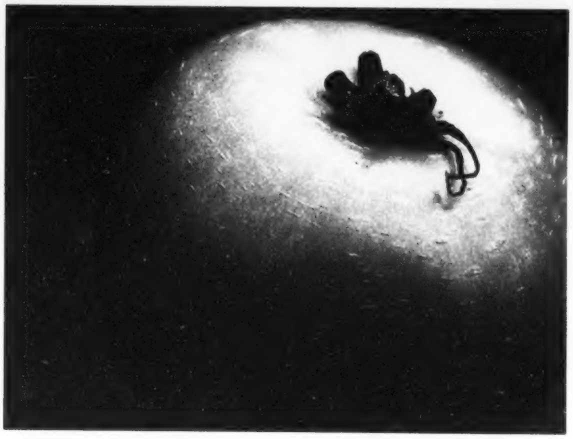


Plate 62. Russetting.

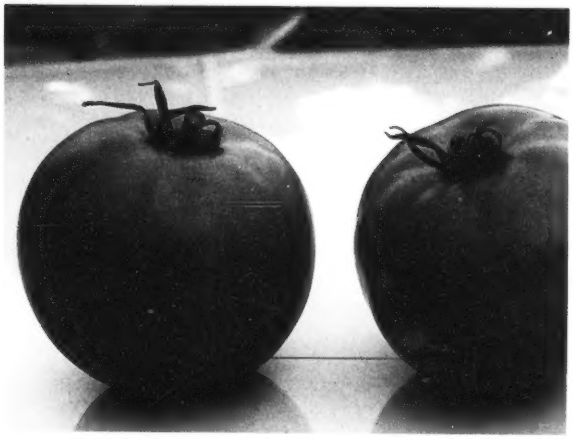


Plate 63. Green shoulder.

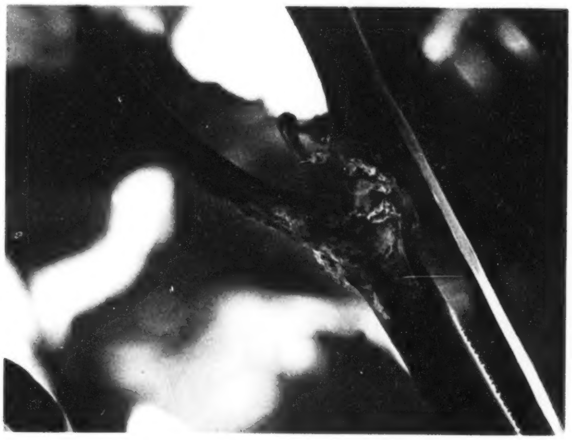


Plate 64. Grey mould.

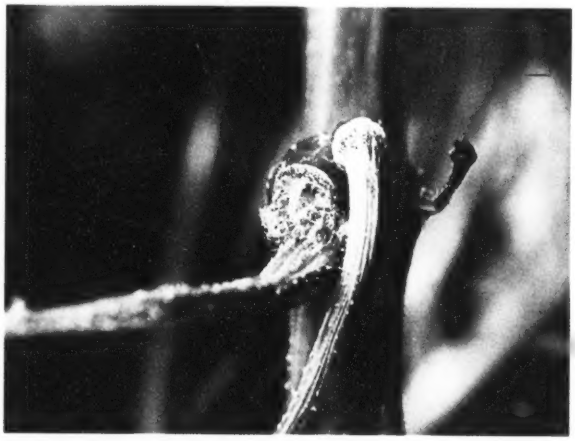


Plate 65. Gummy stem blight on stem.

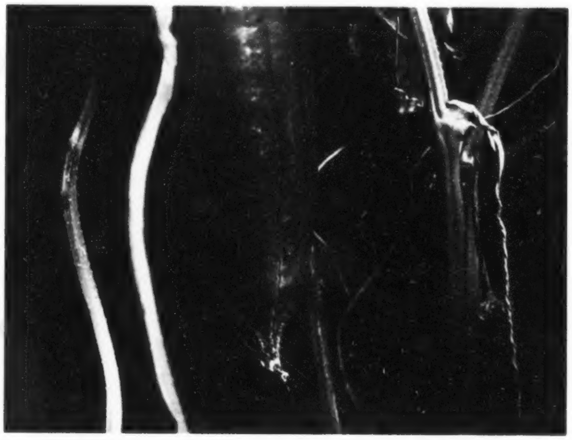


Plate 66. Gummy stem blight on fruit.

Plate 67. Penicillium stem rot.

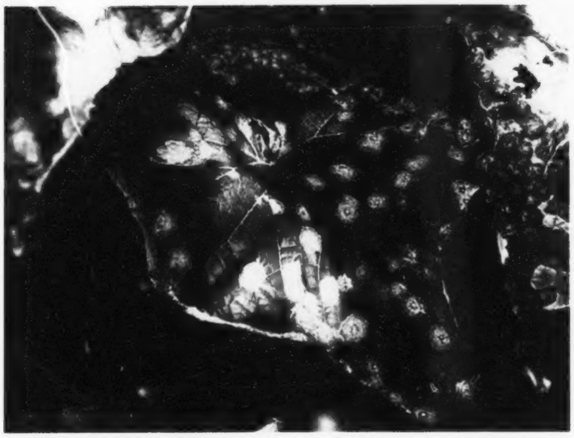


Plate 68. Leaf spot.

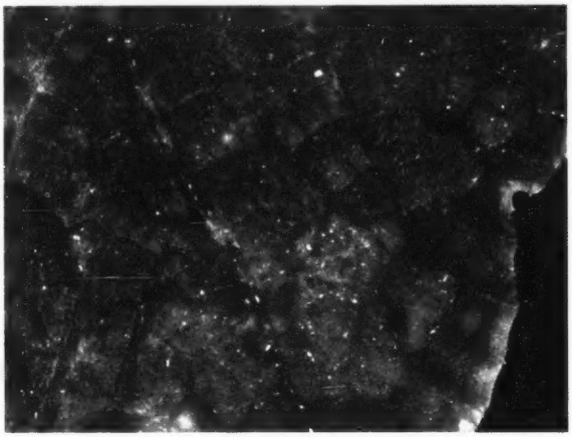


Plate 69. Powdery mildew on cucumbers.

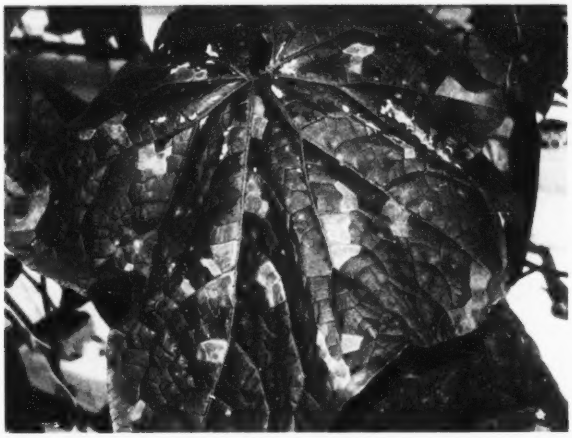


Plate 70. Cucumber downy mildew.

Plate 71. Fusarium wilt of cucumbers.

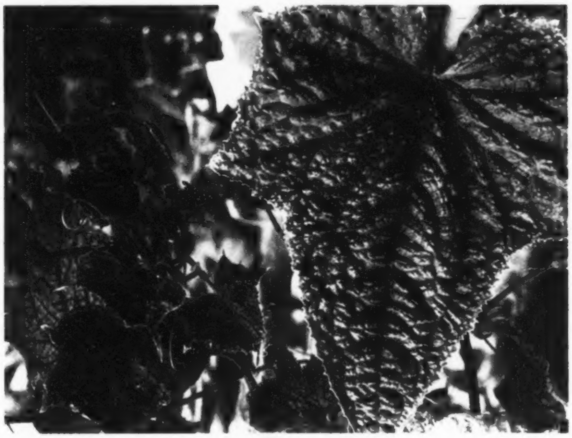


Plate 72. Cucumber mosaic on leaf.

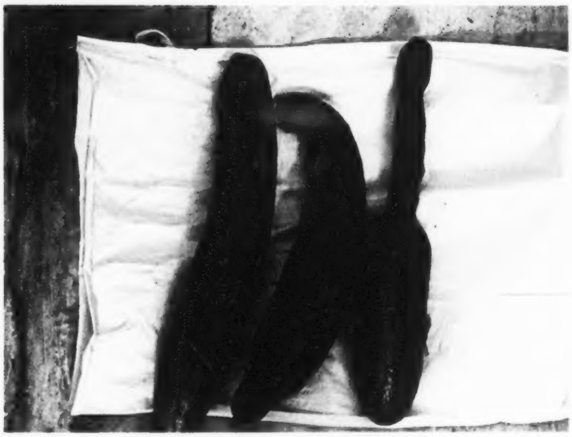


Plate 73. Cucumber mosaic on fruit.

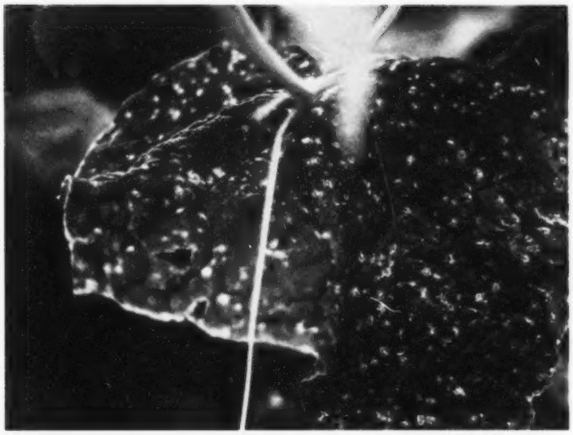


Plate 74. Early symptoms of cucumber necrosis virus in cucumber.

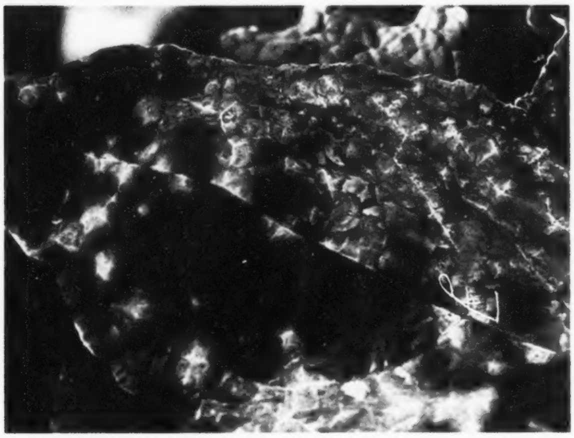


Plate 75. Late symptoms of cucumber necrosis virus in cucumber.

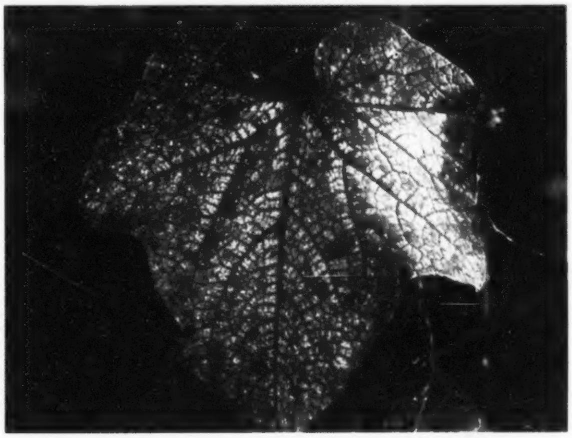


Plate 76. Beet pseudo-yellows virus.

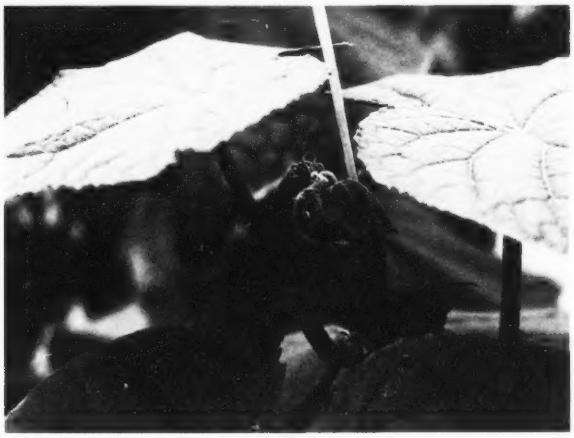


Plate 77. Loss of growing point caused by calcium deficiency due to low calcium supply and rapid growth on young cucumber shoots.

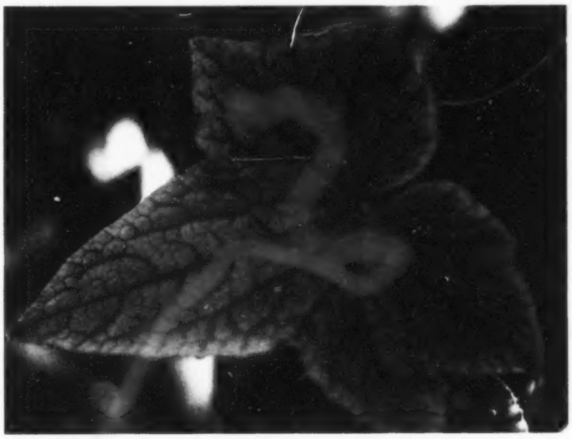


Plate 78. Young cucumber leaf showing iron deficiency symptoms due to rapid growth and heavy fruit load.

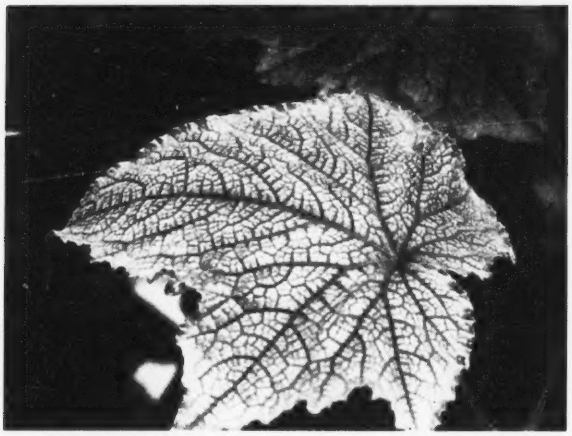


Plate 79. Iron deficiency.

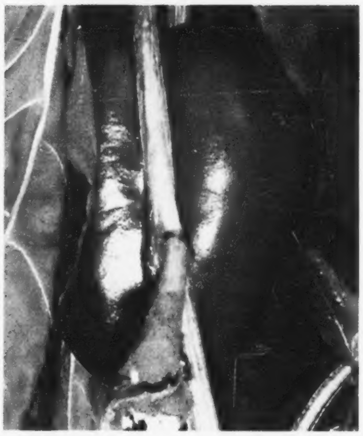


Plate 80. Botrytis rot.

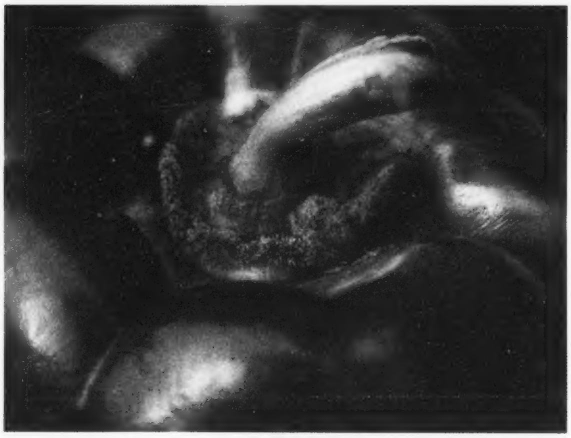


Plate 81. *Botrytis* on pepper fruit.

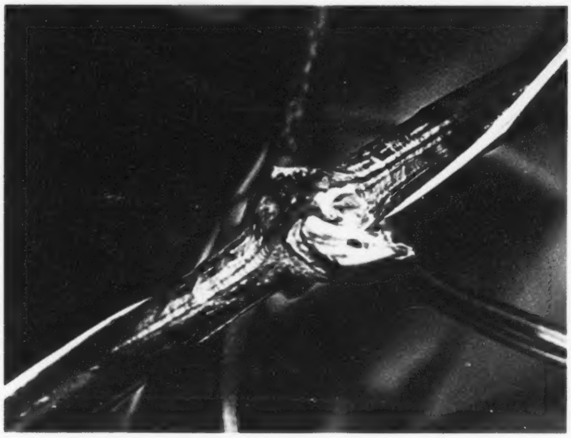


Plate 82. Stem symptoms of Fusarium stem and fruit rot.

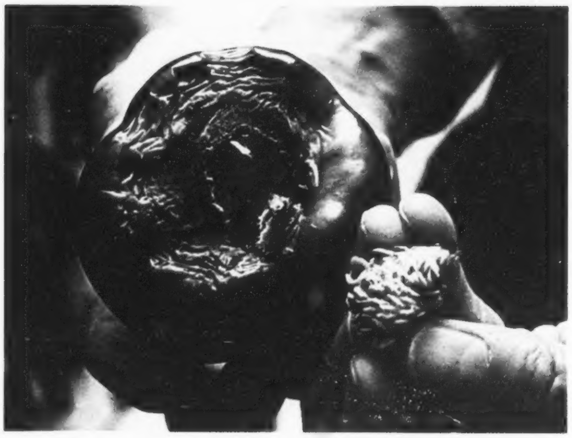


Plate 83. Fruit symptoms of Fusarium stem and fruit rot.

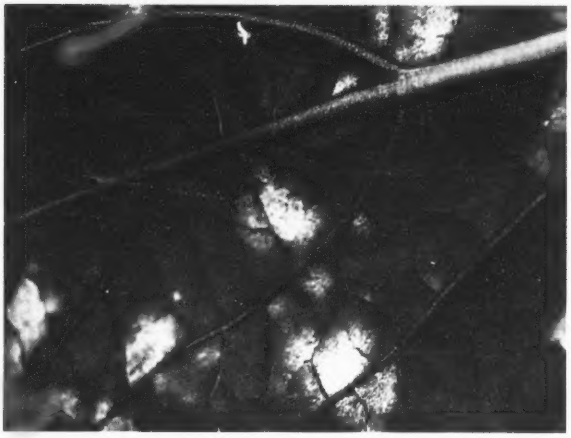


Plate 84. Powdery mildew.

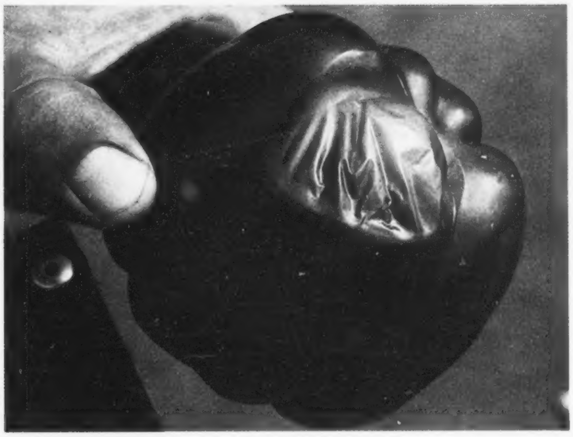


Plate 85. Bacterial soft rot of peppers.

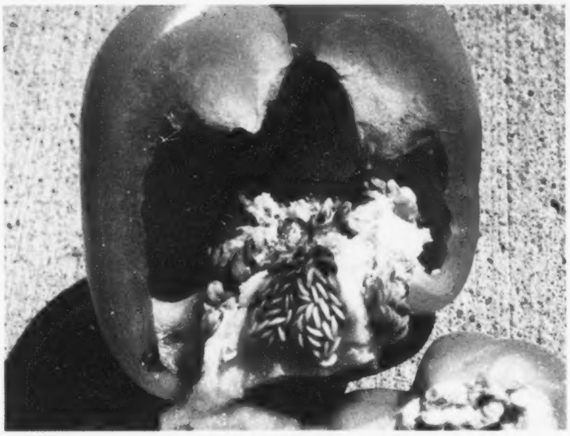


Plate 86. Internal fruit rot in pepper.

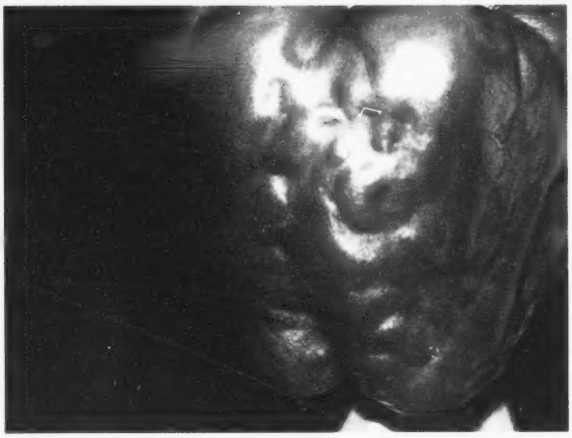


Plate 87. Pepper mild mottle virus.

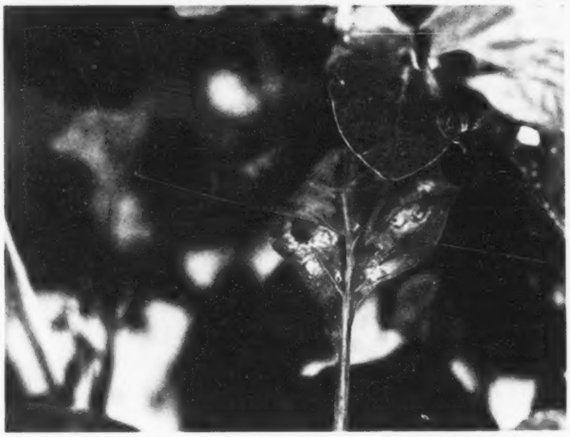


Plate 88. Leaf symptoms of tomato spotted wilt virus in pepper.

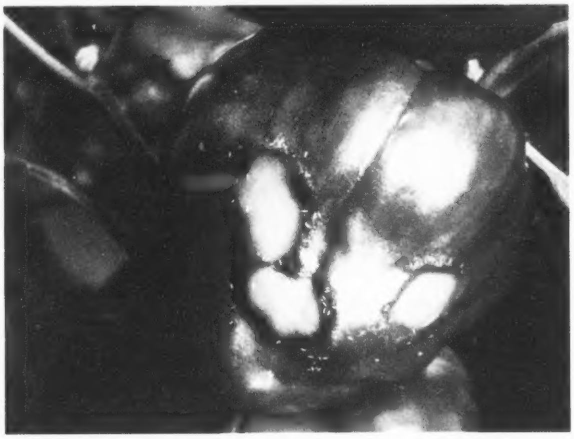


Plate 89. Blossom end rot.

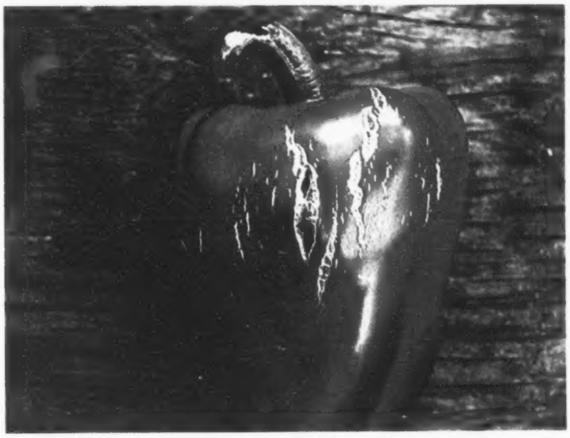


Plate 90. Fruit cracking due to internal growth.

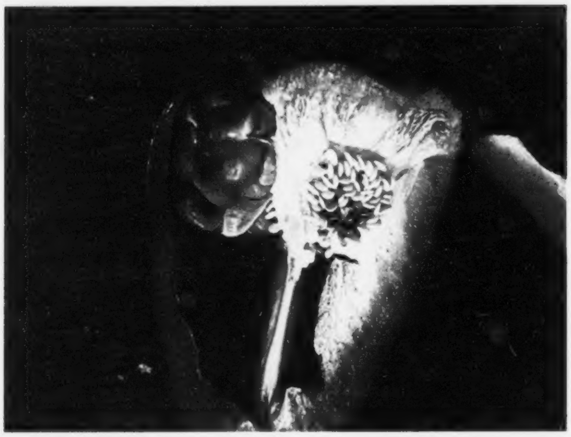


Plate 91. Fruit cracking due to internal growth (cross-section).

Plate 92. Silvering on pepper fruit.

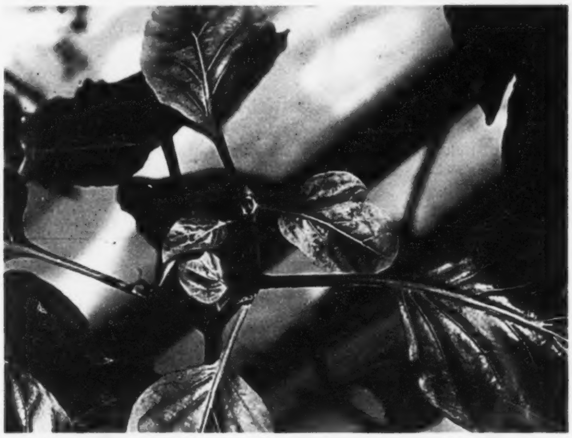


Plate 93. Manganese deficiency.

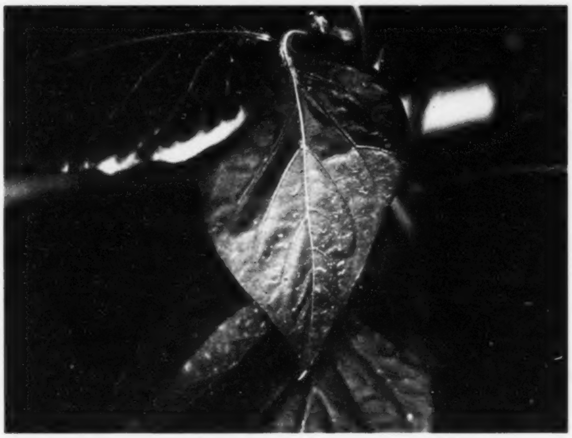


Plate 94. Boron deficiency.

Plate 95. *Botrytis* on eggplant fruit.

Plate 96. Sepal ring on eggplant, resulting in unmarketable fruit.

Plate 97. Western flower thrips (lower left) and *Echinothrips* (upper right).

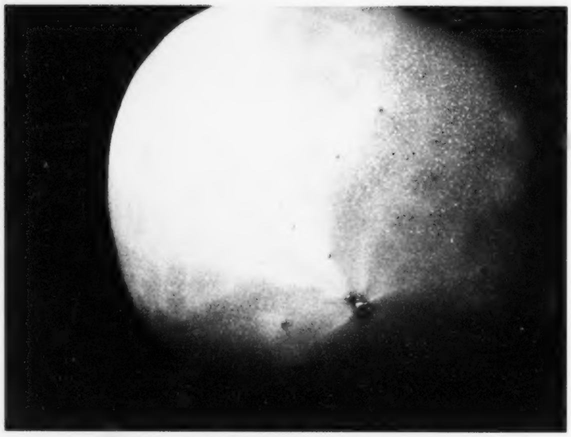


Plate 98. Thrips damage to fruit, oviposition damage.

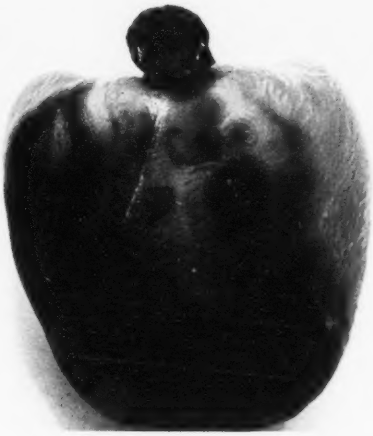


Plate 99. Tomato spotted wilt virus.

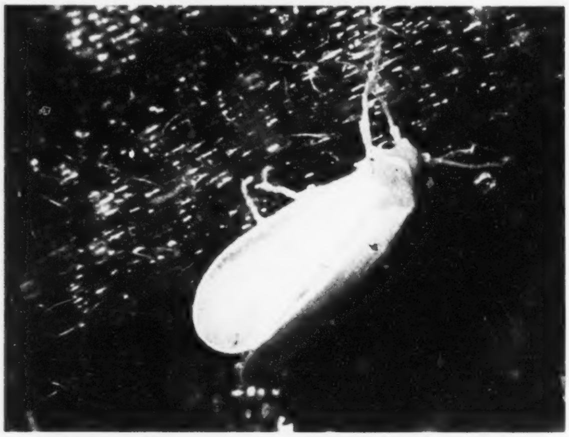


Plate 100. Whiteflies.

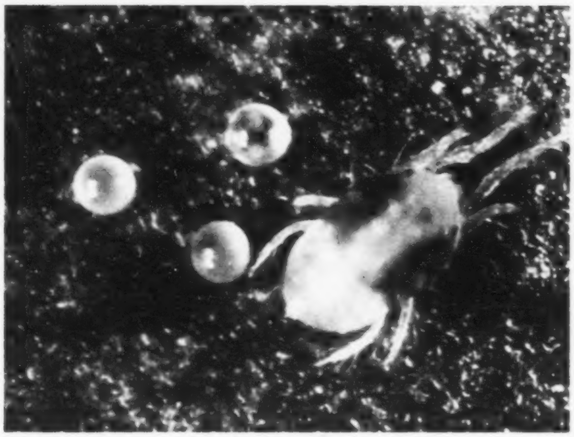


Plate 101. Two-spotted spider mite with eggs.

Plate 102. Two-spotted spider mite damage on cucumbers.

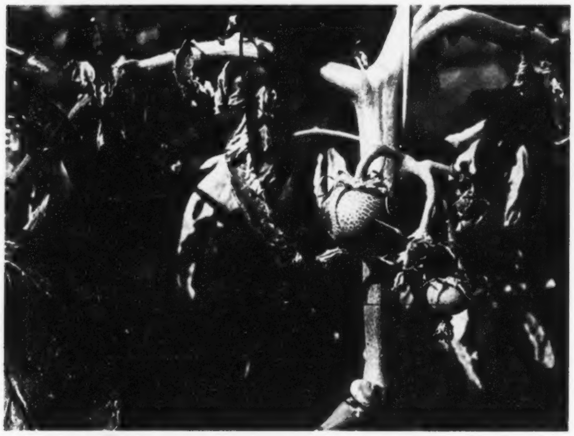


Plate 103. Tomato russet mite on stem.

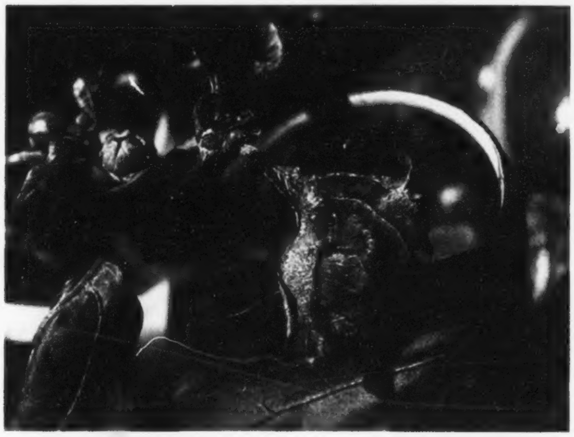


Plate 104. Feeding damage symptoms due to cyclamen mite on peppers.

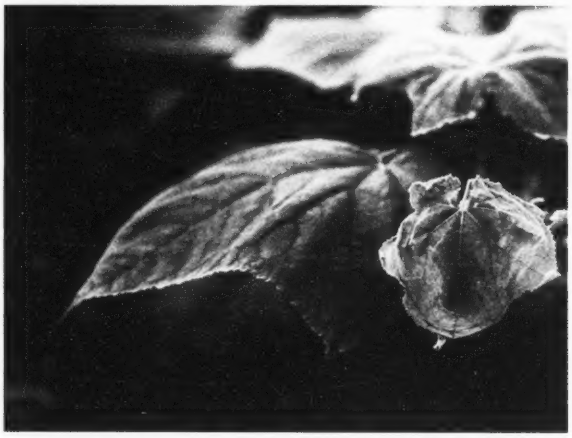


Plate 105. Feeding damage symptoms due to broad mites on cucumber.

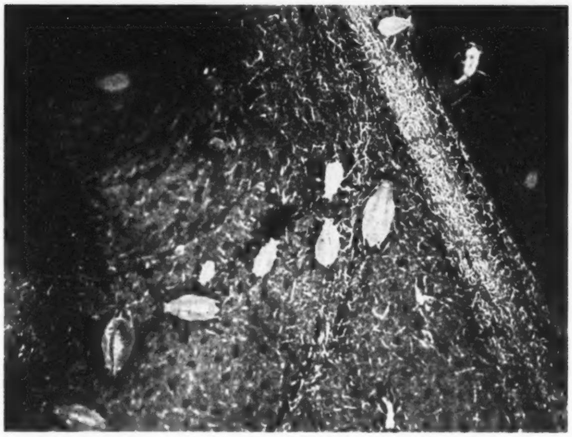


Plate 106. Green peach aphids.

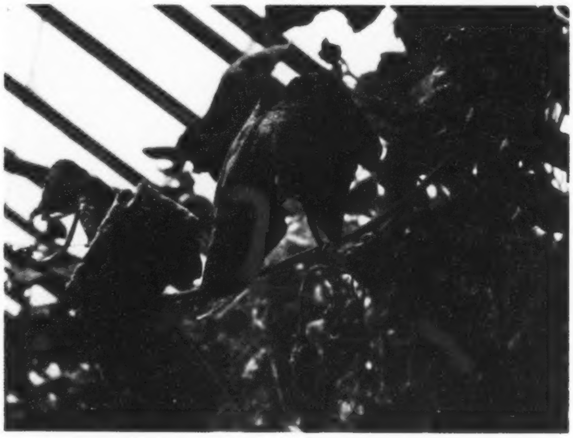


Plate 107. Sooty mould caused by aphid infestation on cucumbers.

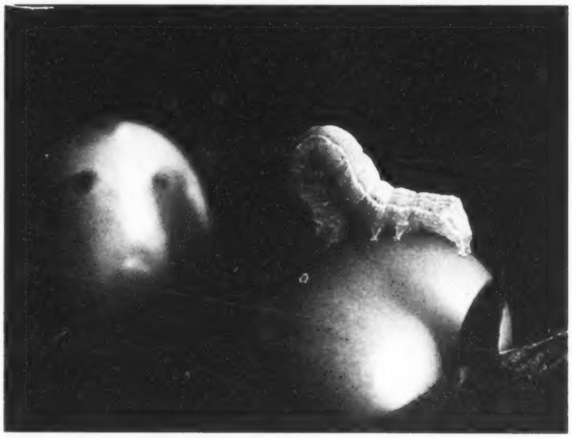


Plate 108. Cabbage loopers.

Plate 109. Lygus bug.

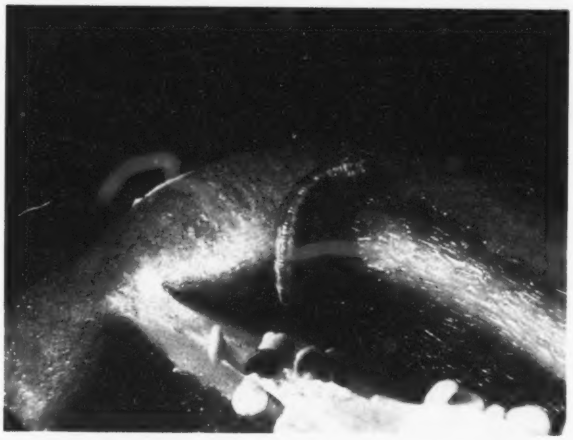


Plate 110. European corn borer.

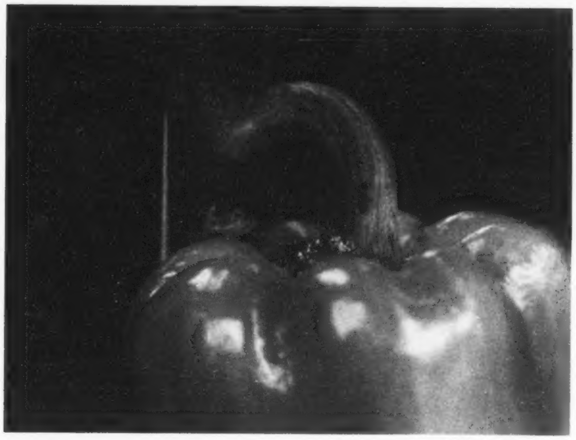


Plate 111. Visual damage caused by European corn borer in peppers.

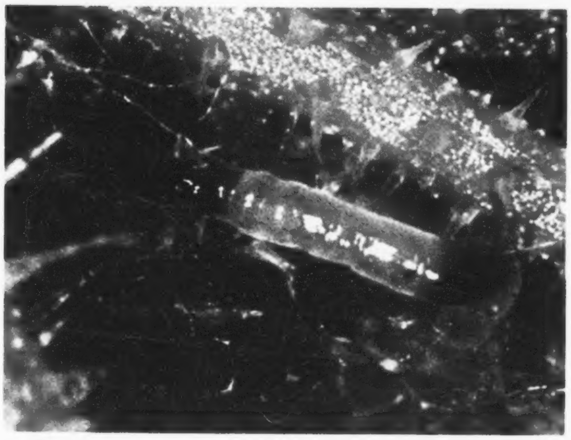


Plate 112. Fungus gnat.

Plate 113. Adult rove beetle.

Plate 114. Leaf damage caused by tomato pinworm.

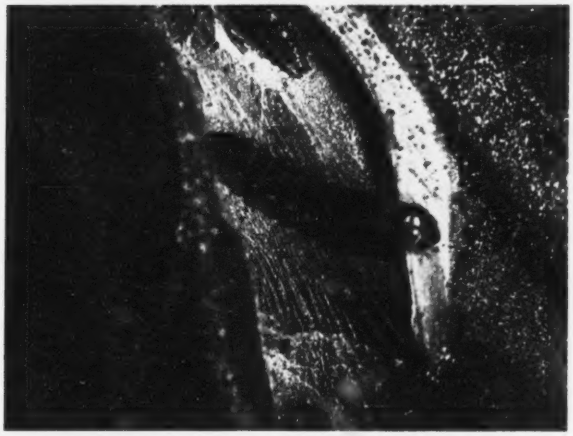


Plate 115. Close-up of tomato pinworm larvae.

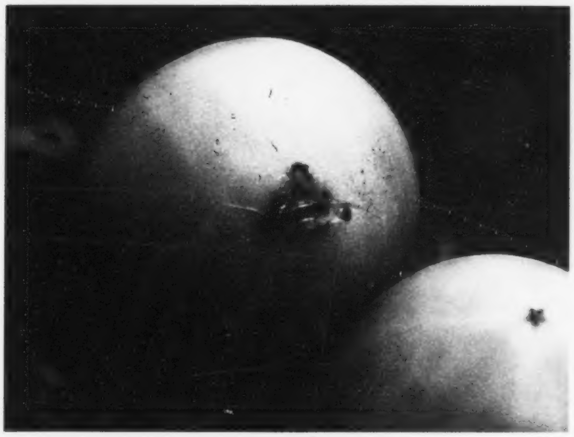


Plate 116. Fruit damage caused by tomato pinworm.

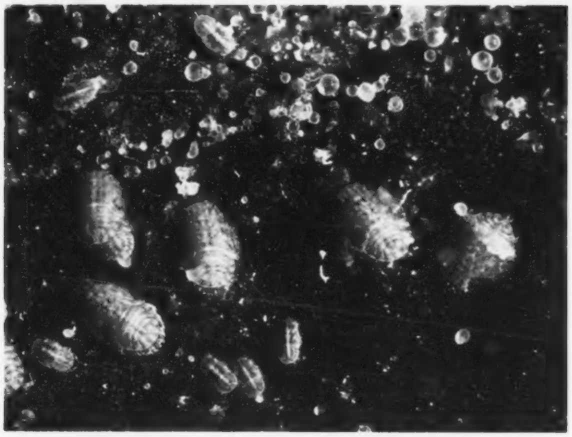


Plate 117. Nymphal stages of potato psyllids.

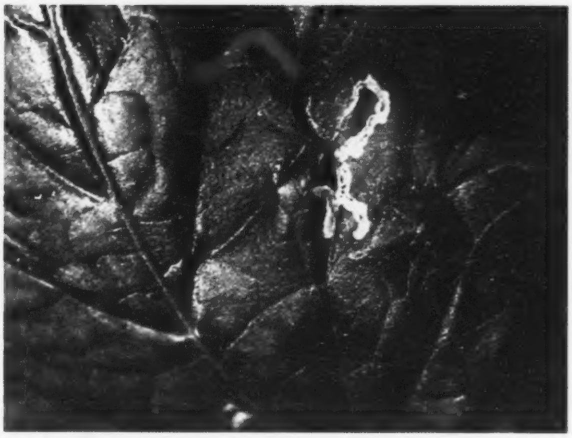
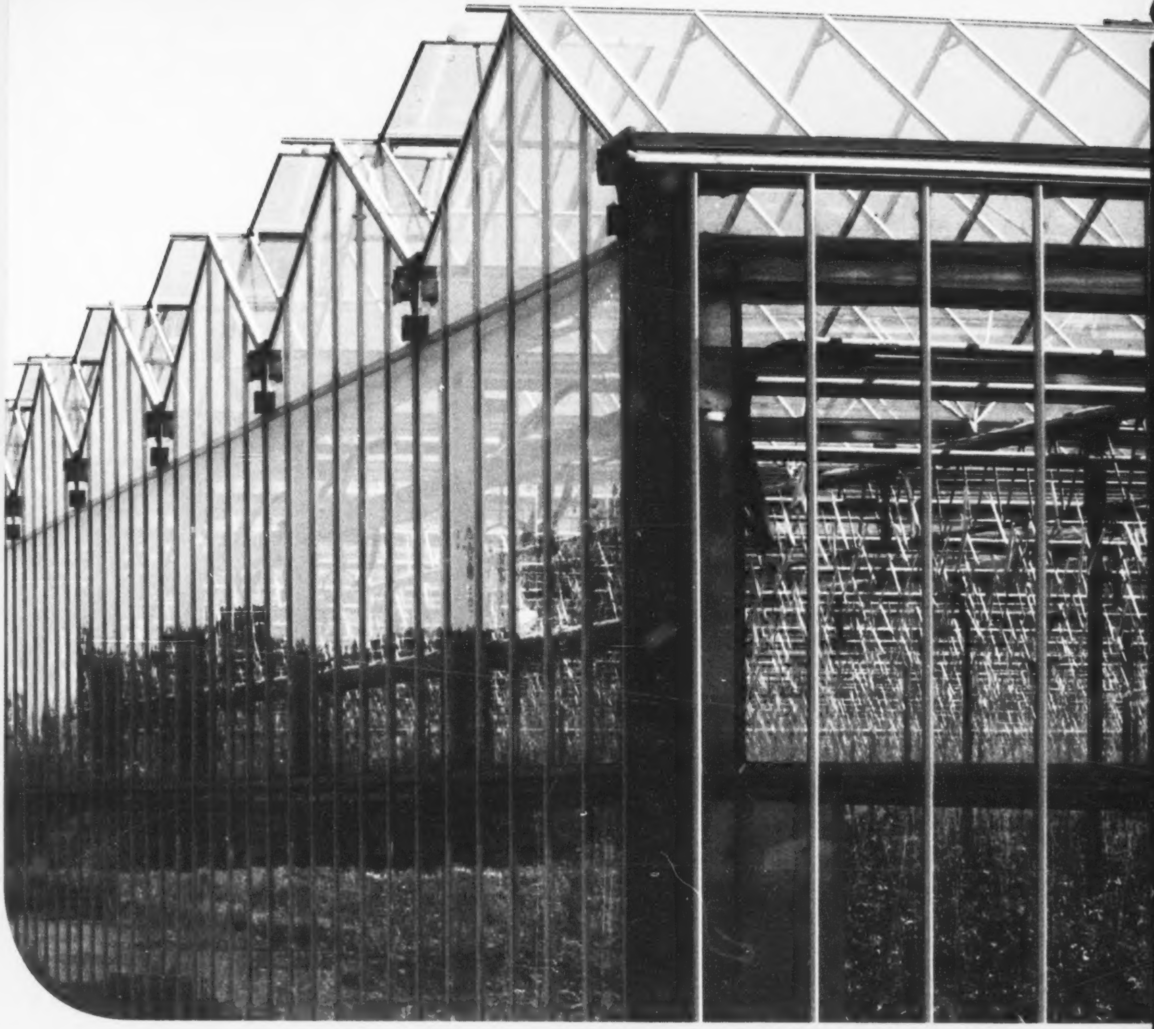
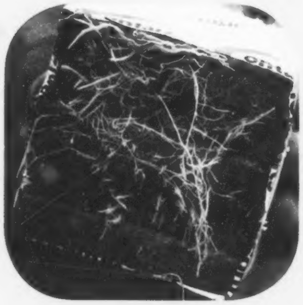
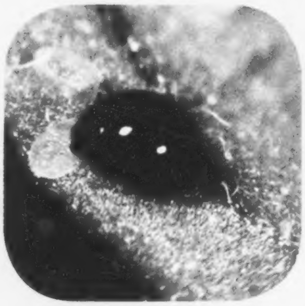


Plate 118. Leafminer damage on tomato.







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